Working Group 3

Reunião de 14/12/22

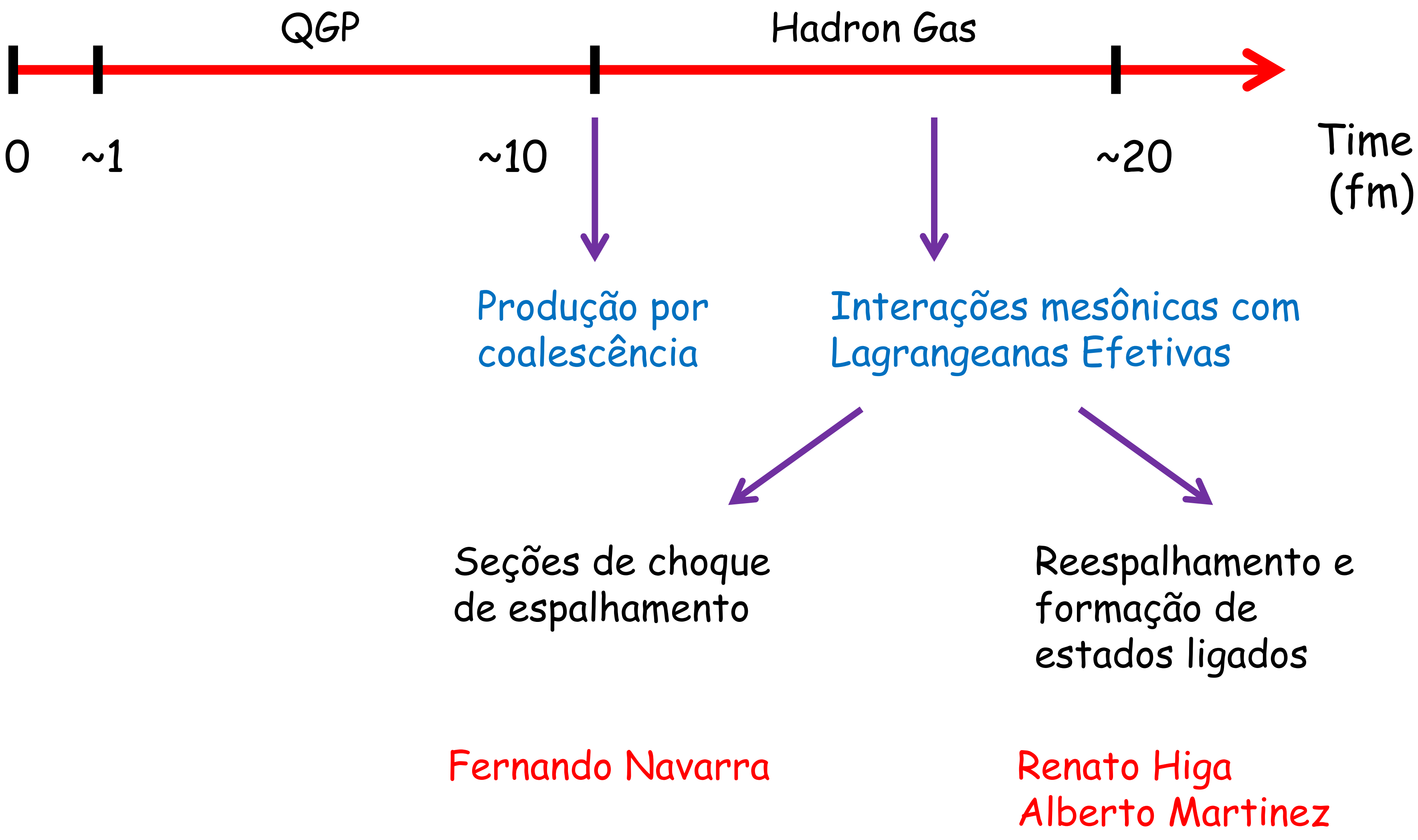
Atividades no segundo semestre de 2022

Fernando Navarra

Alberto Martinez

Renato Higa

Linha do tempo de uma colisão de ions pesados

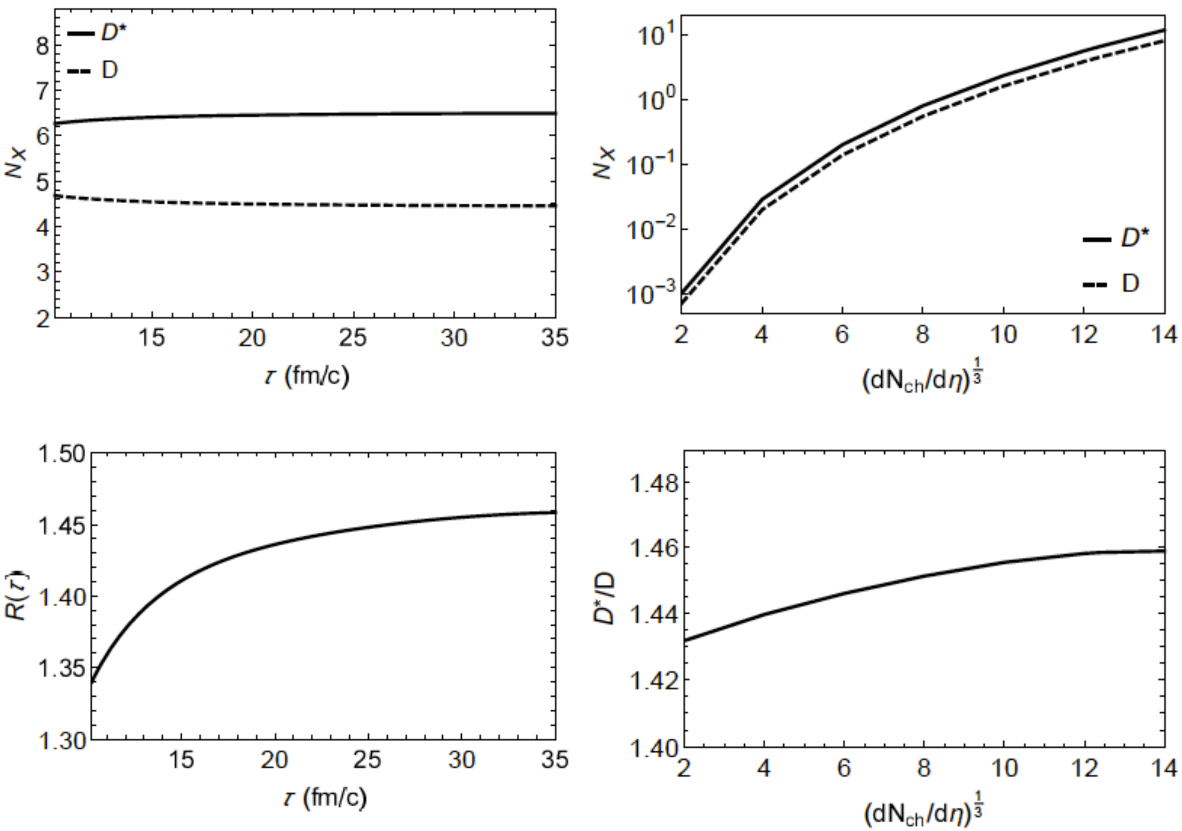


Fernando Navarra

Trabalhos e andamento e publicados

Estudo da produção e interações do Zcs (3985) : em andamento

Estudo da produção e interações do D* e D : concluido e publicado



Interação melhorada com regras de soma da QCD

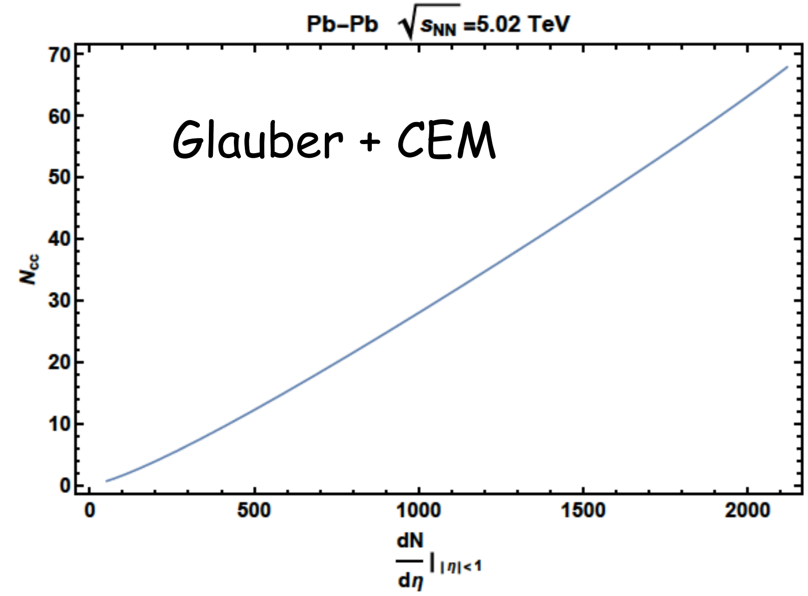
Abreu, FSN and Vieira,
Phys. Rev. D 106, 074028 (2022)

Produção de exóticos com charme no modelo de coalescência

Trabalho de mestrado de Richard Terra

Número de pares c-cbar em função do tamanho do sistema

Melhoria do trabalho da colaboração EXHIC



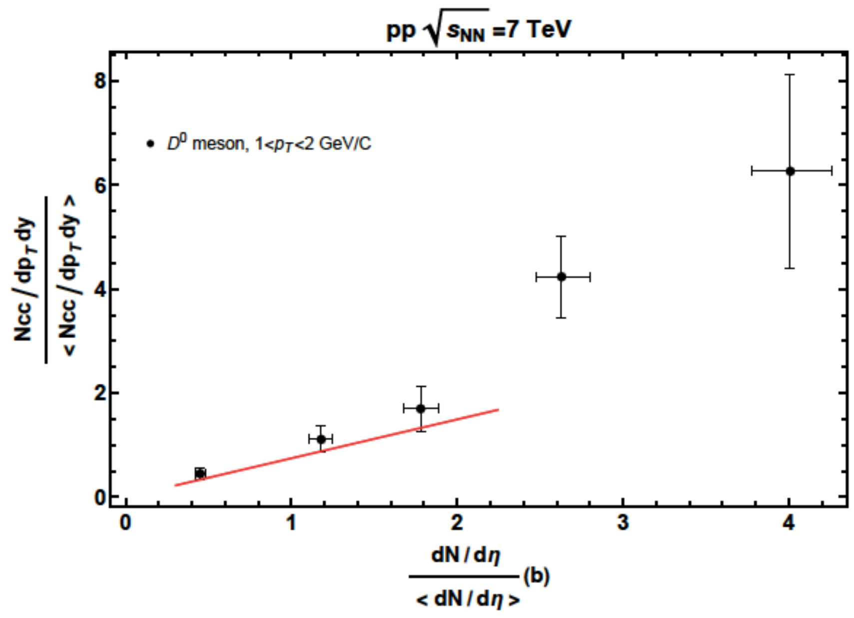
Produção de charme em proton - proton

Crescimento mais rápido do que o esperado

Color Glass Condensate?

Hidrodinâmica?

Multiple parton scattering?



Distribuição de multiplicidade de mesons com charme em proton-proton

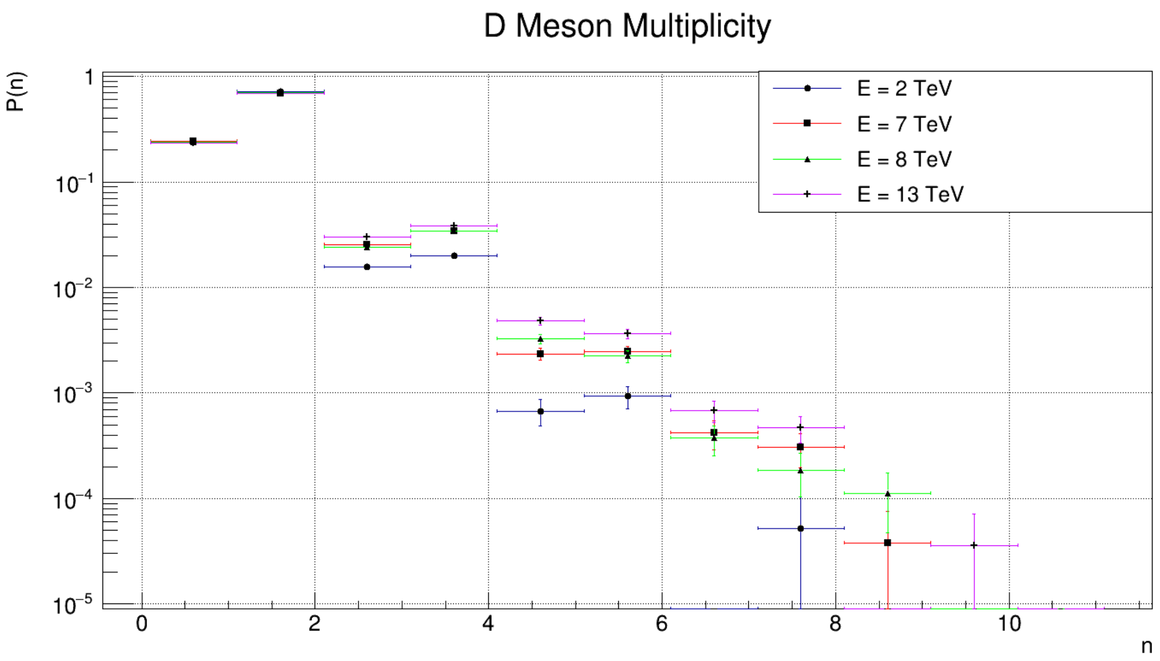
Trabalho de Jhoão Arneiro (doutorando do Suaide)

Simulação com PYTHIA

Comparação com NBD

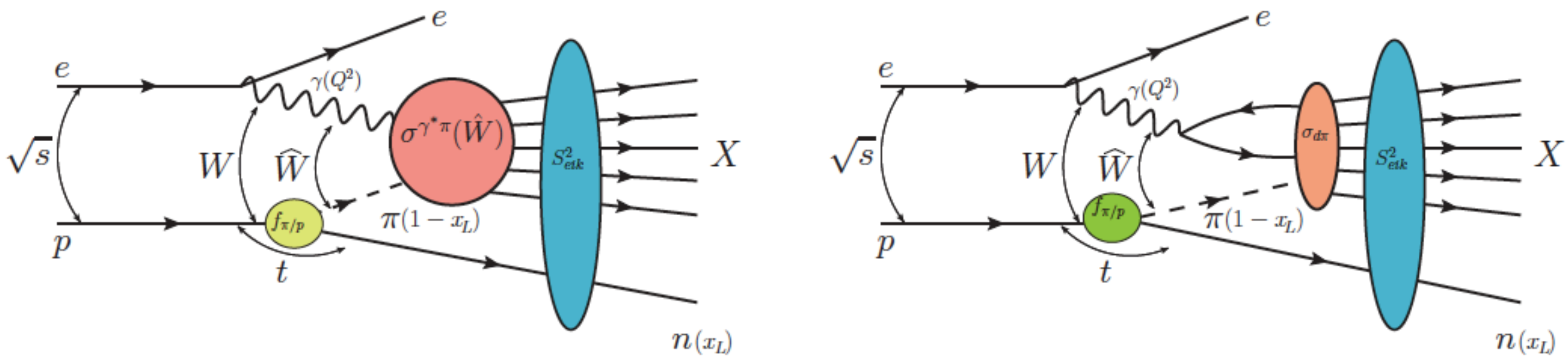
Altas densidades ?

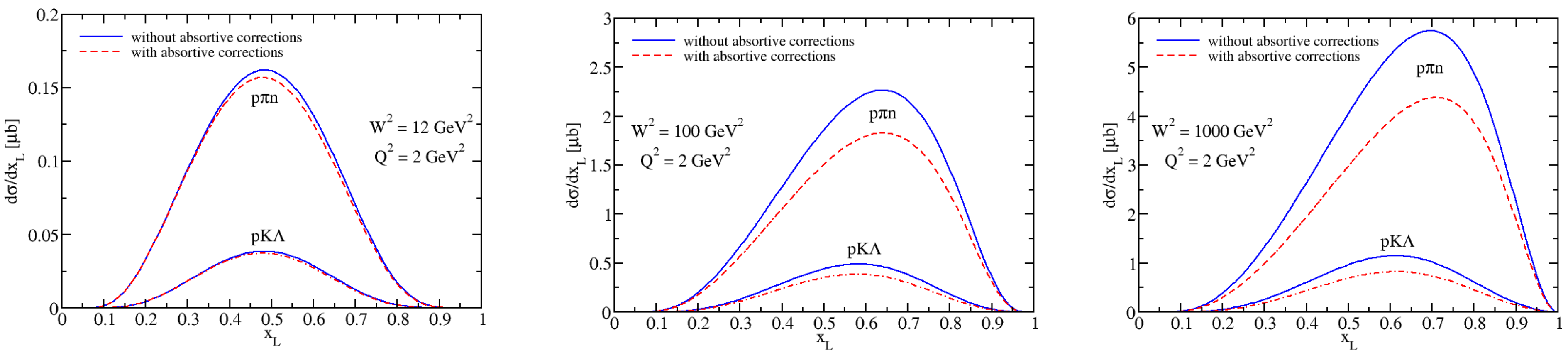
Multiple parton scattering ?



Leading neutrons e leading Lambdas no Electron Ion Collider

Trabalho de Diego Spiering (pós-doc)





Publicações em Proceedings

System size dependence of the K^*/K ratio at LHC energies #3

Chiara Le Roux (Sao Paulo U.), Fernando Silveira Navarra (Sao Paulo U.), Luciano Melo Abreu (Bahia U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 043 • Contribution to: Hadron Physics 2020, 043

pdf DOI cite claim reference search 0 citations

Multiplicity moments at the LHC: how bad is the negative binomial distribution ? #4

Guilherme Germano (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 063 • Contribution to: Hadron Physics 2020, 063

pdf DOI cite claim reference search 0 citations

A Simple Approach to the Charmonium Spectrum #5

Ríchard Terra (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 056 • Contribution to: Hadron Physics 2020, 056

pdf DOI cite claim reference search 0 citations

Absorptive corrections in leading neutron production #6

Fabiana Carvalho (Sao Paulo U.), Victor Goncalves (Pelotas U.), Fernando Silveira Navarra (Sao Paulo U.), Diego Spiering (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 053 • Contribution to: Hadron Physics 2020, 053

pdf DOI cite claim reference search 0 citations

The tension between radius and deformability in quark stars #7

Milena Bastos Albino (Sao Paulo U.), Fernando Silveira Navarra (Unlisted, BR), Ricardo Fariello (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 044 • Contribution to: Hadron Physics 2020, 044

pdf DOI cite claim reference search 0 citations

Magnetic transitions in ultraperipheral collisions #8

Isabella Danhoni (Sao Paulo U.), F. Navarra (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 067 • Contribution to: Hadron Physics 2020, 067

pdf DOI cite claim reference search 0 citations

Participação em conferências

QCD-22, Montpellier, França, julho de 2022

Heavy Flavor - 22, Torino, Itália, julho de 2022

Non-Equilibrium Dynamics - 22, Krabi, Tailândia, dezembro de 2022

Orientações

Guilherme Germano (doutoramento)

Richard Terra (mestrado)

Fernando César Sobrinho (mestrado)

Henrique Fontes (mestrado)

Renato Higa

Participação em conferências

Reunião de Trabalho em Física Nuclear no Brasil

Simpósio do INCT-FNA

Orientações

Alberto Fernandez (iniciação científica)

Efeito de canais acoplados e estrutura analítica da matriz S aplicada ao X(3872)

Alberto Martinez

Trabalhos publicados e submetidos

1) Exotic states with triple charm
M. Bayar, A. Martínez Torres, K. P. Khemchandani, R. Molina, E. Oset,
arxiv: 2211.09294 [hep-ph]

2) $D_1(2420)$ and its interactions with a kaon: open charm states with strangeness
Brenda B. Malabarba, K. P. Khemchandani, A. Martínez Torres, E. Oset,
arxiv: 2211.16222 [hep-ph]

Publicações em Proceedings

1) Exotic properties of $N^*(1895)$ and its impact on the photo production of light hyperons,
K. P. Khemchandani, A. Martínez Torres, Sang-Ho Kim, Seung-il Nam, A. Hosaka,
Acta Physical. Polon. A 142, 329 (2022)

2) Studying the process $\gamma d\to\pi^0\eta d$,
A. Martínez Torres, K. P. Khemchandani, E. Oset,
Acta Physical. Polon. A 142, 378 (2022).

Participação em conferências

1) 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine, 10-15 July 2022, Krakow, Poland

Visitas científicas

21 Agosto-10 Setembro 2022, IFIC-Universidade de Valencia, Valencia, Espanha.

4-15 Novembro 2022, Universidade Complutense de Madri, Madri, Espanha.

Orientações

Brenda Malabarba, doutoramento

Victor Roberto Soares da Silva, iniciação científica

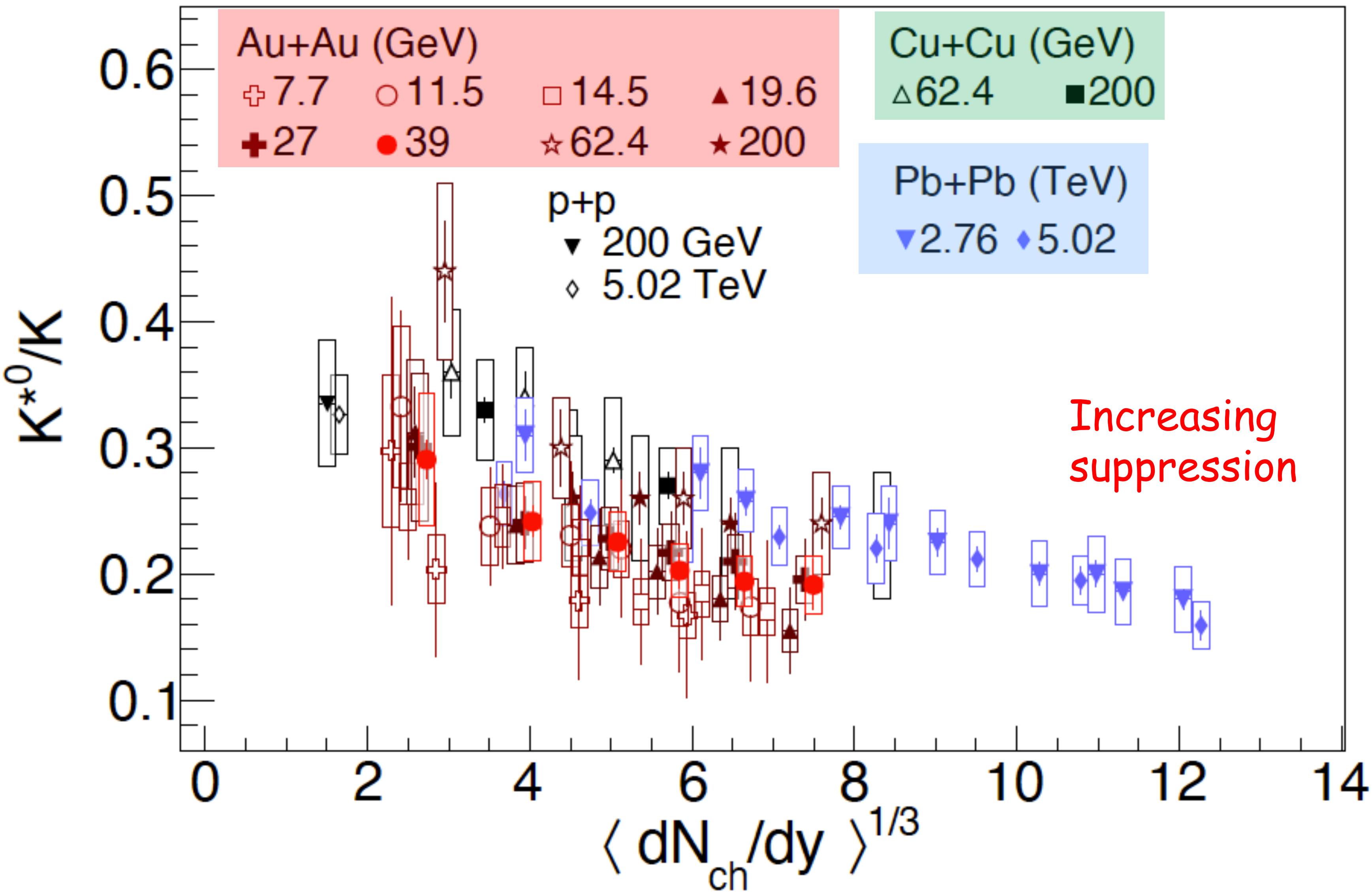
Novo projeto

Estudo do estado $\phi(2170) = \phi\,\bar{K}\,K$

$$\phi(2170) = \phi\,\bar{K}\,K$$

Estudo do decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$. Recentemente, as colaborações Belle e BESIII tem medido o decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$ como um jeito de obter informação da natureza do estado $\phi(2170)$. Os dados obtidos mostram que o estado $\phi(2170)$ não seria compatível com as predições que existem para esses decaimentos considerando $\phi(2170)$ como estado quark-antiquark ou híbrido. No nosso modelo, $phi(2170)$ seria um estado molecular de $\phi K\bar K$ que poderia decair em $\phi\eta$ e $\phi\eta^\prime$ através da formação de $f_0(980)$ no sistema $K\bar K$, $\pi\pi$, $\eta\eta$ e $\eta\eta^\prime$.

...to a wealthy of data



STAR, arXiv:2210.02909

What can we learn from this ratio?

Interactions of K and K* in a hot hadron gas

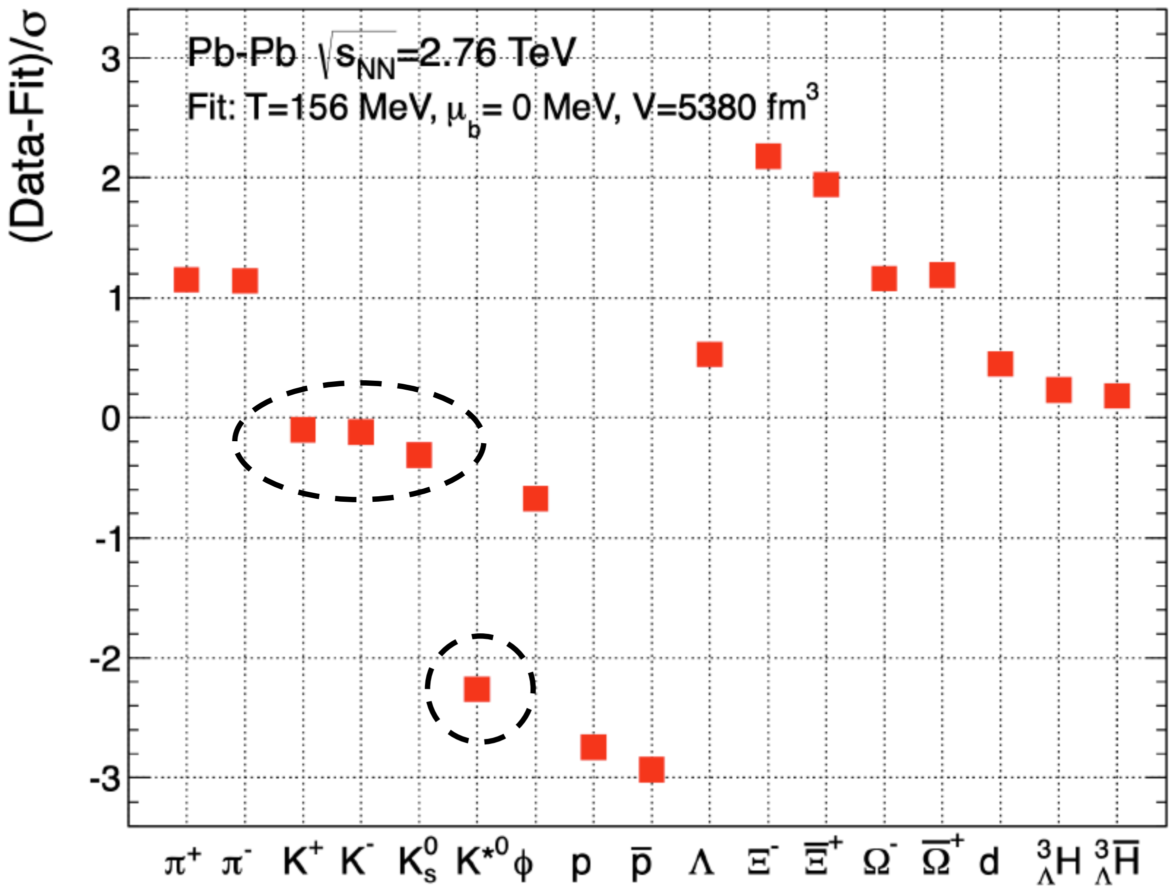
Emergence of chemical equilibrium (freeze-out)

Kinetic freeze-out: lifetime of the hadron gas phase

Confirm the existence of a hot hadron gas

Do we have a good theory ?

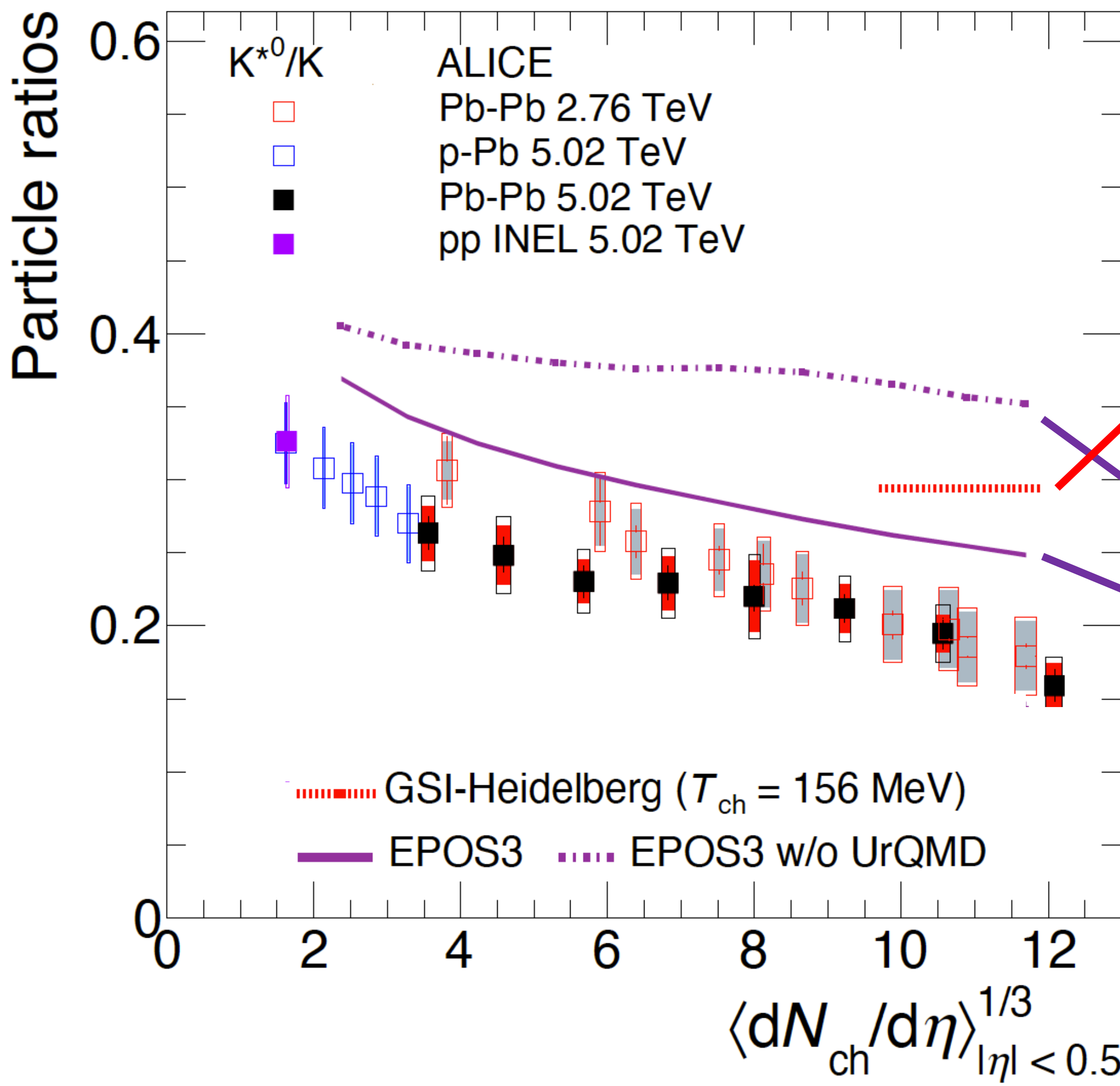
Statistical Hadronization Model fails...



Stachel et al.,
arXiv:1311.4662

We must include rescattering and/or decay !

ALICE, arXiv:1910.14419

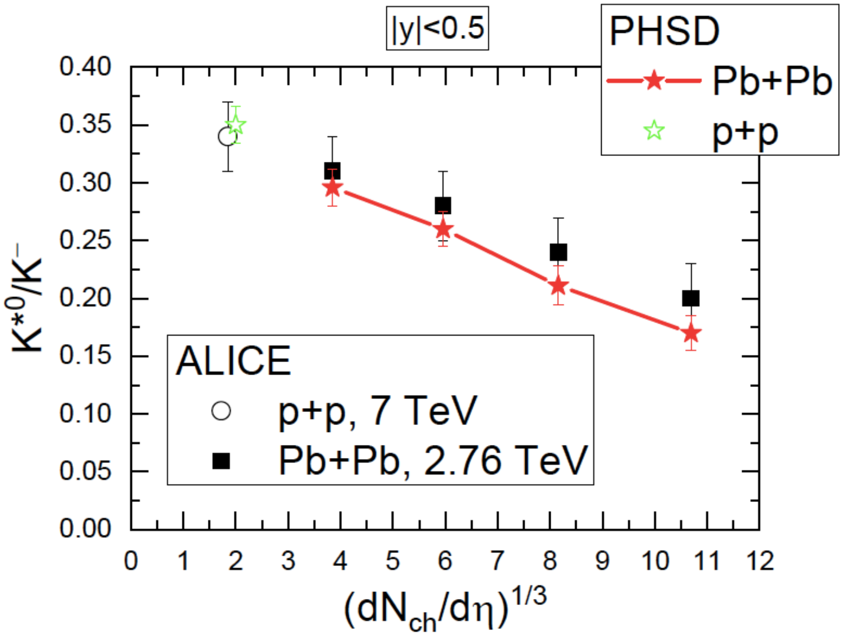


Stachel et al., arXiv:1311.4662

SHM

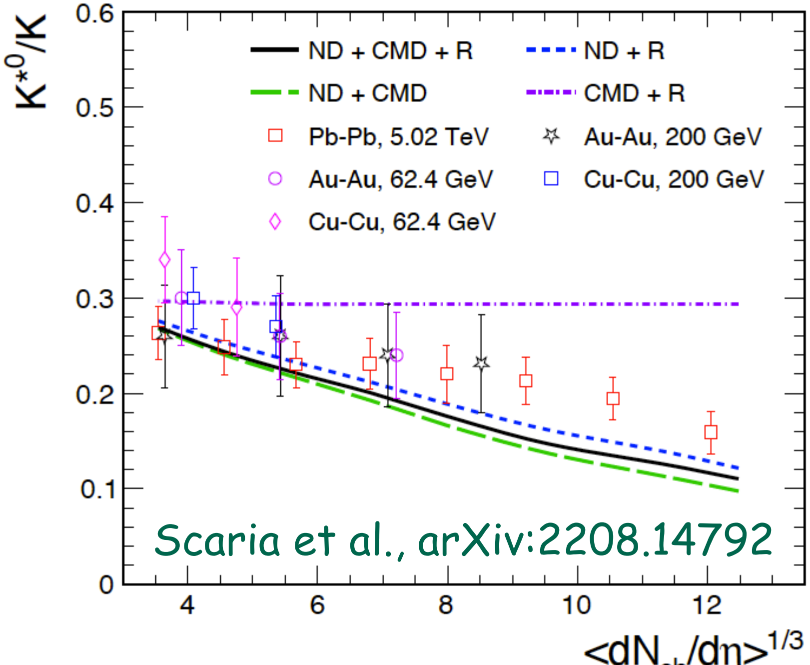
Knospe, Markert, Werner, Steinheimer, Bleicher, arXiv:1509.07895

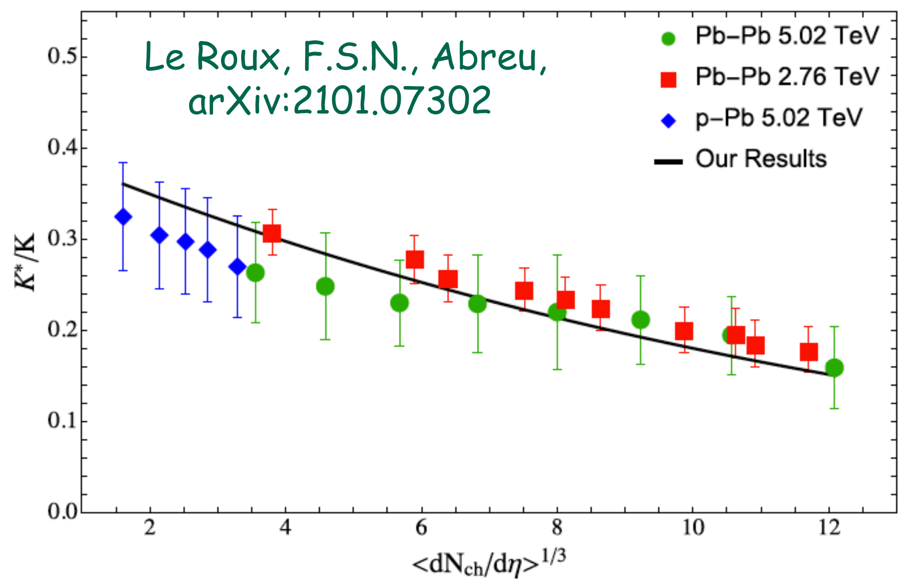
Interactions with the hadron gas improve agreement with data !



Ilner, Cabrera, Markert, Bratkovskaya, arXiv:1609.02778

Ilner, Blair,Cabrera, Markert, Bratkovskaya, arXiv:1707.00060





The hadron gas contribution

Start with the multiplicities at the hadronization

Study the changes produced by interactions in the hadron gas

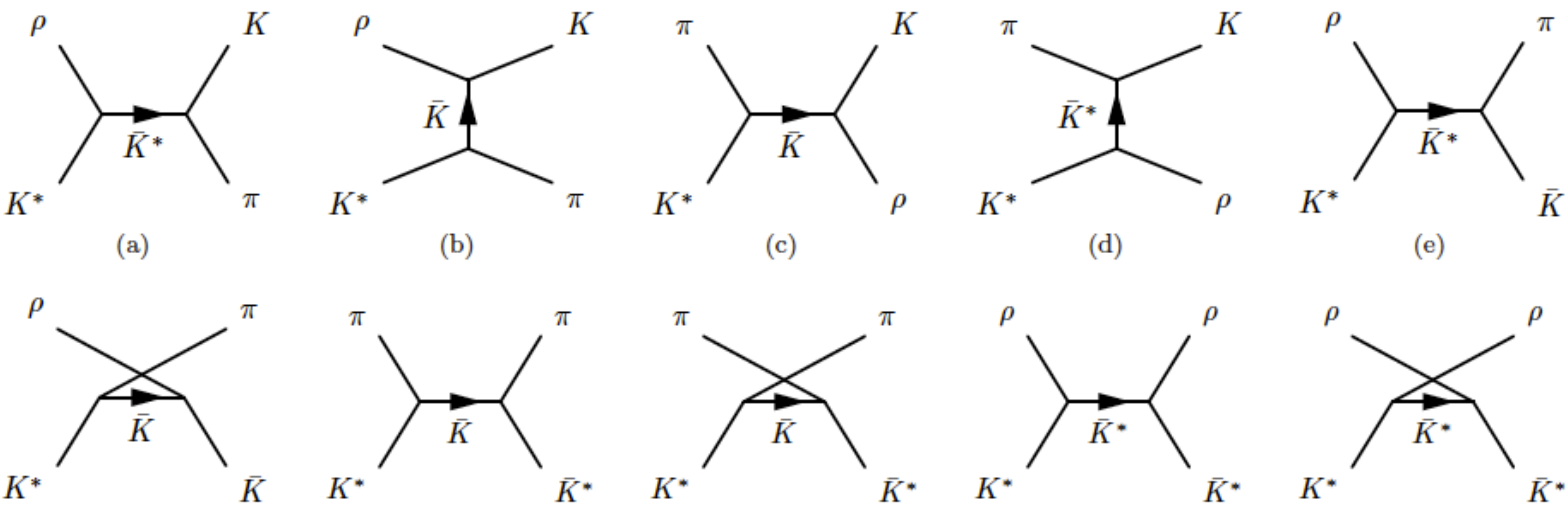
Lagrangians -> Amplitudes -> Cross Sections -> Thermal Cross Sections

Evolution equations -> Expansion and cooling -> Freeze-out

K and K* interactions with light hadrons

$$
\begin{aligned}
\mathcal{L}_{\pi K K^*} &= i g_{\pi K^* K} K^{*\mu} \vec{\tau} \cdot (\bar{K} \partial_\mu \vec{\pi} - \partial_\mu \bar{K} \vec{\pi}) \\
\mathcal{L}_{\rho K K} &= i g_{\rho K K} (K \vec{\tau} \partial_\mu \bar{K} - \partial_\mu K \vec{\tau} \bar{K}) \cdot \vec{\rho}^\mu, \\
\mathcal{L}_{\rho K^* K^*} &= i g_{\rho K^* K^*} \, [(\partial_\mu K^{*\nu} \vec{\tau} \bar{K}^*_\nu - K^{*\nu} \vec{\tau} \partial_\mu \bar{K}^*_\nu) \cdot \vec{\rho}^\mu \\
&+ (K^{*\nu} \vec{\tau} \cdot \partial_\mu \vec{\rho}_\nu - \partial_\mu K^{*\nu} \vec{\tau} \cdot \vec{\rho}_\nu) \bar{K}^{*\mu} \\
&+ K^{*\mu} (\vec{\tau} \cdot \vec{\rho}^\nu \partial_\mu \bar{K}^*_\nu - \vec{\tau} \cdot \partial_\mu \vec{\rho}^\nu \bar{K}^*_\nu)],
\end{aligned}
$$

S. Cho and S.H. Lee, arXiv:1509.04092



Cross Sections : $$\sigma = \frac{1}{64\pi^2 s g_1 g_2} \frac{|\vec{p}_f|}{|\vec{p}_i|} \int d\Omega \overline{|\mathcal{M}|^2} F^4$$

Form Factors : $$F_{u,t}(\vec{q}) = \frac{\Lambda^2 - m_{ex}^2}{\Lambda^2 + \vec{q}^2} \qquad \Lambda = 1.8\,\mathrm{GeV}$$

Thermal Cross Sections : $$\langle \sigma_{ab\to cd}\, v_{ab} \rangle = \frac{\int d^3\mathbf{p}_a d^3\mathbf{p}_b\, f_a(\mathbf{p}_a)\, f_b(\mathbf{p}_b)\, \sigma_{ab\to cd}\;v_{ab}}{\int d^3\mathbf{p}_a d^3\mathbf{p}_b\, f_a(\mathbf{p}_a)\, f_b(\mathbf{p}_b)}$$

$$f_i(\vec{p}_i) = \frac{1}{e^{\sqrt{\vec{p}_i^{\,2} + m_i^2}/T} - 1} \qquad v_{ab} = \sqrt{(p_a \cdot p_b)^2 - m_a^2 m_b^2}/(E_a E_b)$$

Inverse processes with detailed balance:

$$g_a g_b |\vec{p}_{ab}|^2 \sigma_{ab\to cd}(s) = g_c g_d |\vec{p}_{cd}|^2 \sigma_{cd\to ab}(s)$$

Rate equations

$$\frac{dN_{K^*}}{d\tau} = \langle\sigma_{K\rho\to K^*\pi}v_{K\rho}\rangle n_\rho(\tau)N_K(\tau) - \langle\sigma_{K^*\pi\to K\rho}v_{K^*\pi}\rangle n_\pi(\tau)N_{K^*}(\tau) + \langle\sigma_{K\pi\to K^*\rho}v_{K\pi}\rangle n_\pi(\tau)N_K(\tau)$$
$$- \langle\sigma_{K^*\rho\to K\pi}v_{K^*\rho}\rangle n_\rho(\tau)N_{K^*}(\tau) + \langle\sigma_{\pi\rho\to K^*\bar{K}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau) - \langle\sigma_{K^*\bar{K}\to\rho\pi}v_{K^*\bar{K}}\rangle n_{\bar{K}}(\tau)N_{K^*}(\tau)$$
$$+ \langle\sigma_{\pi\pi\to K^*\bar{K}^*}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{K^*\bar{K}^*\to\pi\pi}v_{K^*\bar{K}^*}\rangle n_{\bar{K}^*}(\tau)N_{K^*}(\tau) + \langle\sigma_{\rho\rho\to K^*\bar{K}^*}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{K^*\bar{K}^*\to\rho\rho}v_{K^*\bar{K}^*}\rangle n_{\bar{K}^*}(\tau)N_{K^*}(\tau) + \langle\sigma_{K\pi\to K^*}v_{K\pi}\rangle n_\pi(\tau)N_K(\tau) - \langle\Gamma_{K^*}\rangle N_{K^*}(\tau),$$

$$\frac{dN_K}{d\tau} = \langle\sigma_{\pi\pi\to K\bar{K}}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{K\bar{K}\to\pi\pi}v_{K\bar{K}}\rangle n_{\bar{K}}(\tau)N_K(\tau) + \langle\sigma_{\rho\rho\to K\bar{K}}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{K\bar{K}\to\rho\rho}v_{K\bar{K}}\rangle n_{\bar{K}}(\tau)N_K(\tau) + \langle\sigma_{K^*\pi\to K\rho}v_{K^*\pi}\rangle n_\pi(\tau)N_{K^*}(\tau) - \langle\sigma_{K\rho\to K^*\pi}v_{K\rho}\rangle n_\rho(\tau)N_K(\tau)$$
$$+ \langle\sigma_{K^*\rho\to K\pi}v_{K^*\rho}\rangle n_\rho(\tau)N_{K^*}(\tau) - \langle\sigma_{K\pi\to K^*\rho}v_{K\pi}\rangle n_\pi(\tau)N_K(\tau) + \langle\sigma_{\pi\rho\to K^*\bar{K}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{K^*\bar{K}\to\rho\pi}v_{K^*\bar{K}}\rangle n_{\bar{K}}(\tau)N_{K^*}(\tau) + \langle\Gamma_{K^*}\rangle N_{K^*}(\tau) - \langle\sigma_{K\pi\to K^*}v_{K\pi}\rangle n_\pi(\tau)N_K(\tau).$$

$$n_i(\tau) = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2dp}{e^{\sqrt{p_i^2+m_i^2}/T(\tau)}-1} \simeq \frac{g_i}{2\pi^2}m_i^2T(\tau)K_2\left(\frac{m_i}{T(\tau)}\right) \qquad N_i = n_i V$$

Expansion and Cooling :

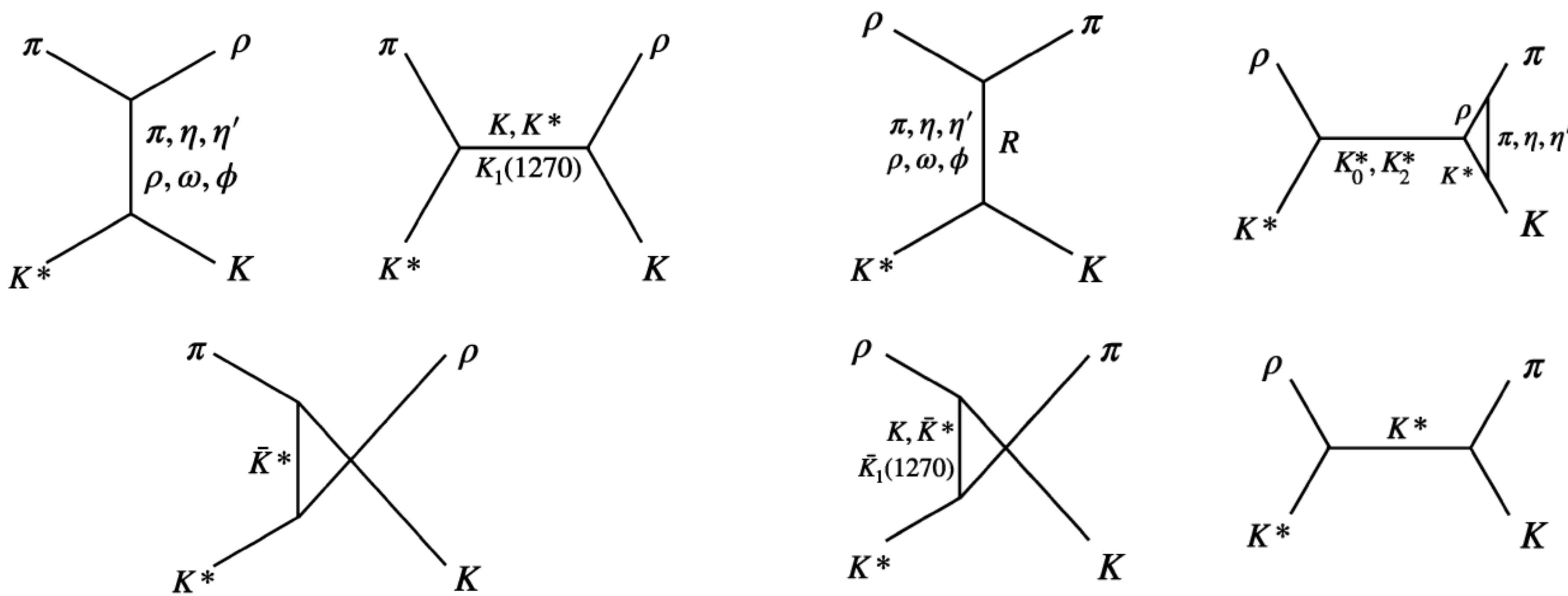
$$\begin{cases} V(\tau) = \pi[R_c + v_c(\tau-\tau_c) + a_c/2(\tau-\tau_c)^2]^2\tau c, \\ T(\tau) = T_c - (T_h - T_f)\left(\dfrac{\tau-\tau_h}{\tau_f-\tau_h}\right)^{4/5}, \end{cases}$$

K and K* interactions with light hadrons improved

Martinez Torres, Khemchandani, Abreu, F.S.N., Nielsen, arXiv:1708.05784

Inclusion of anomalous parity VVP interactions

Exchange of axial resonances

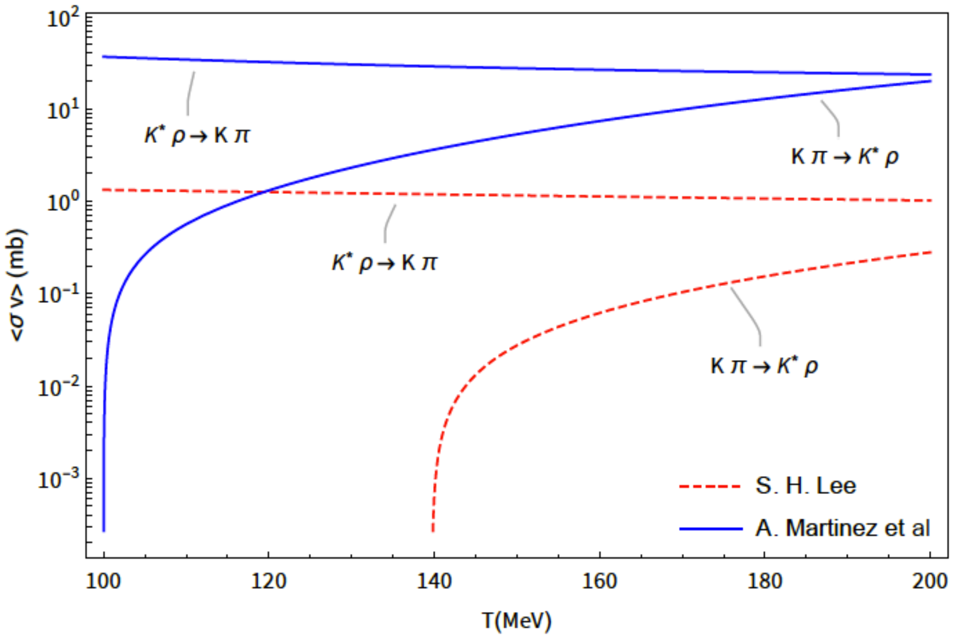


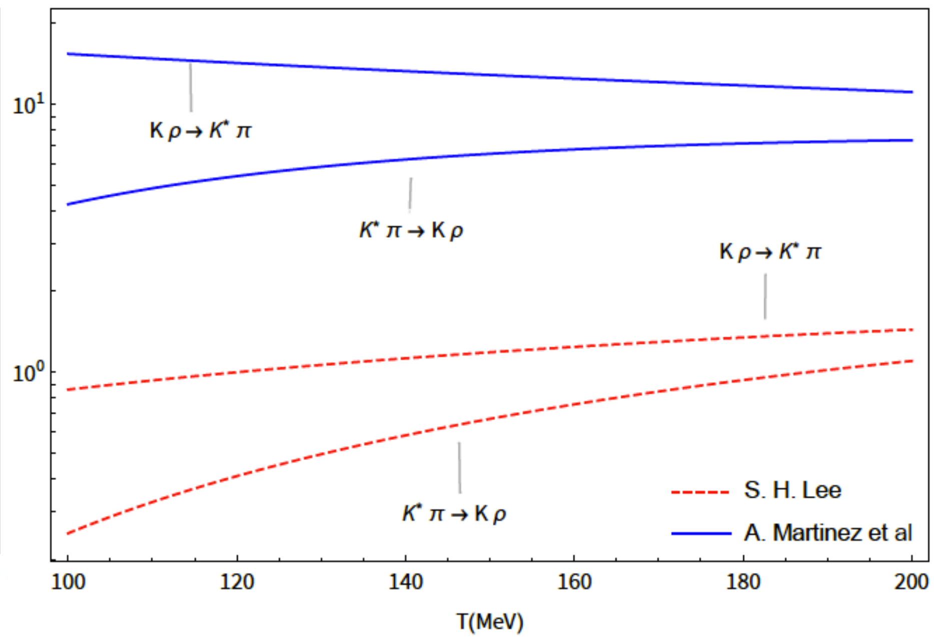
Many processes but only 3 are really important:

$$\begin{cases} K^*\rho \leftrightarrow K\pi \\ K^*\pi \leftrightarrow K\rho \\ K^* \leftrightarrow K + \pi \end{cases}$$

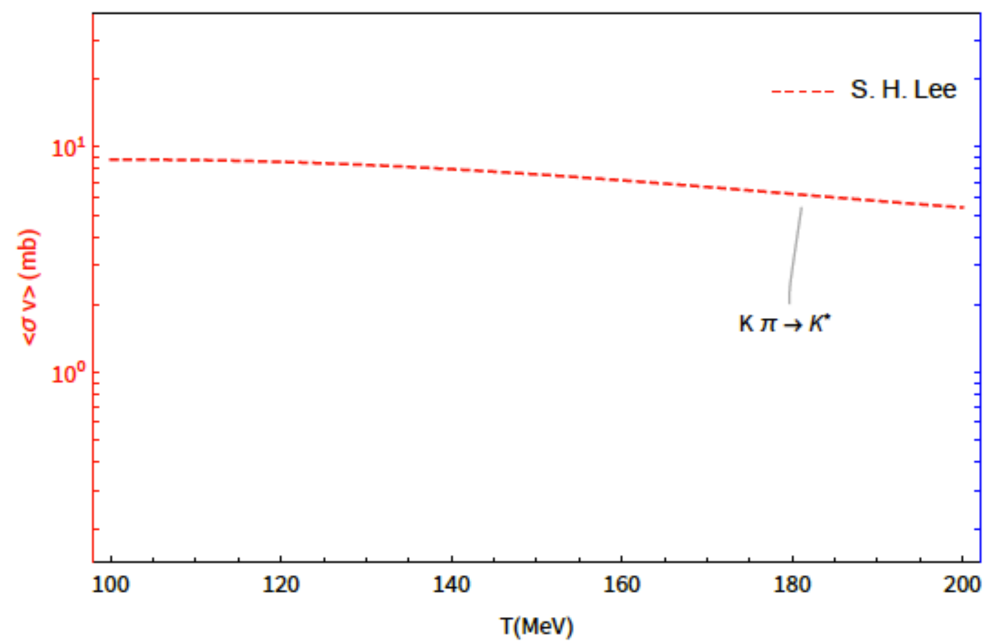
$K^* \rho \leftrightarrow K \pi$

$K^* \pi \leftrightarrow K \rho$





$K^* \leftrightarrow K + \pi$



Simplified evolution equations :

$$\begin{cases} \dfrac{dN_{K^*}(\tau)}{d\tau} = \gamma_K N_K(\tau) - \gamma_{K^*} N_{K^*}(\tau), \\ \dfrac{dN_K(\tau)}{d\tau} = -\gamma_K N_K(\tau) + \gamma_{K^*} N_{K^*}(\tau), \end{cases}$$

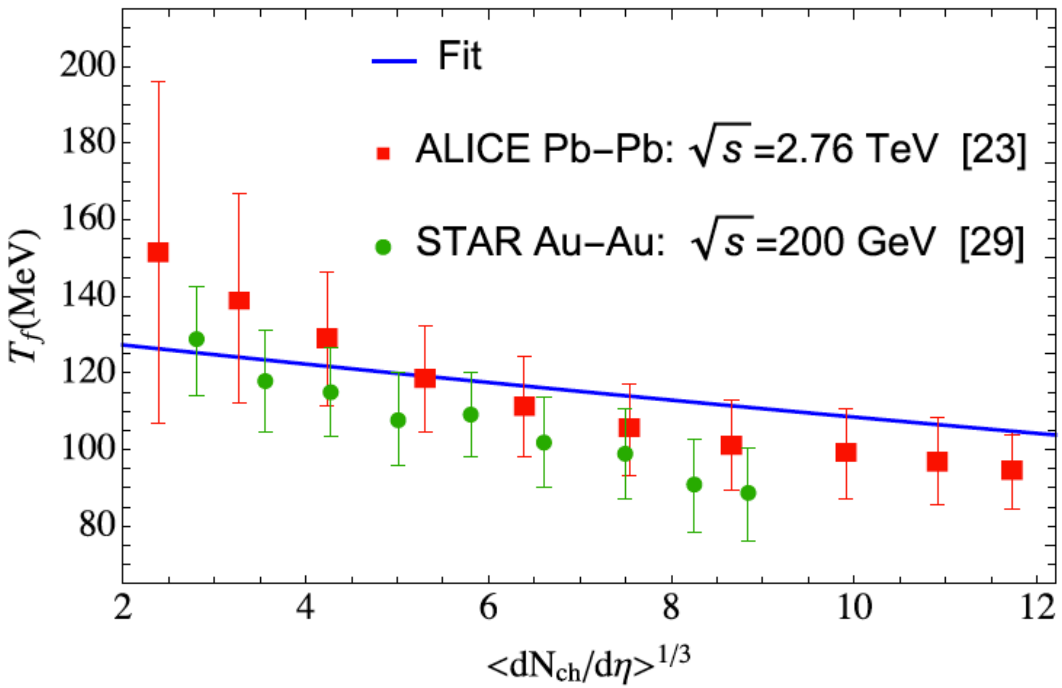
$$\gamma_K = \langle \sigma_{K\pi \to K^*\rho} v_{K\pi} \rangle n_\pi + \langle \sigma_{K\rho \to K^*\pi} v_{K\rho} \rangle n_\rho + \langle \sigma_{K\pi \to K^*} v_{K\pi} \rangle n_\pi ,$$

$$\gamma_{K^*} = \langle \sigma_{K^*\rho \to K\pi} v_{K^*\rho} \rangle n_\rho + \langle \sigma_{K^*\pi \to K\rho} v_{K^*\pi} \rangle n_\pi + \langle \Gamma_{K^*} \rangle .$$

Bjorken cooling : $T = T_h \left(\frac{\tau_h}{\tau} \right)^{1/3}$ → $\tau_f = \tau_h \left(\frac{T_h}{T_f} \right)^3$

T_f depends on the system size : $T_f = T_f \left(\frac{dN}{d\eta}(\eta = 0) \right)$

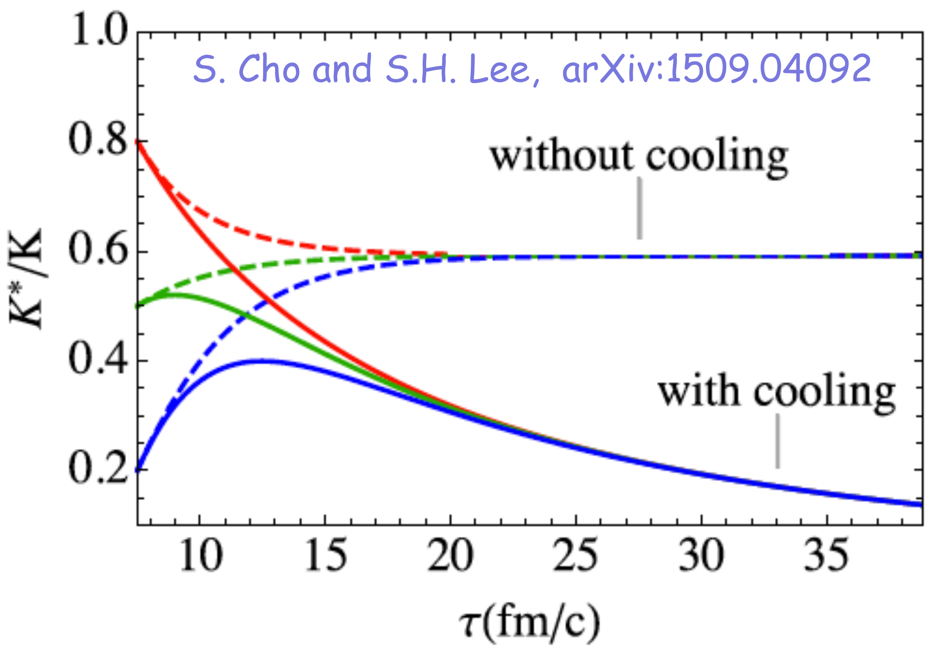
System size dependent freeze-out temperature

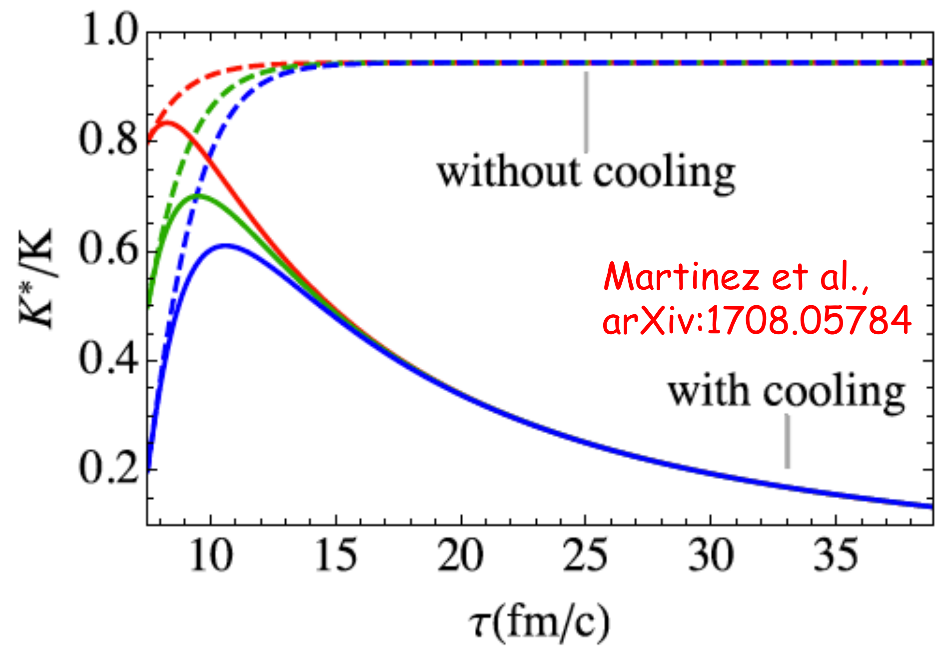


ALICE, arXiv:1303.0737

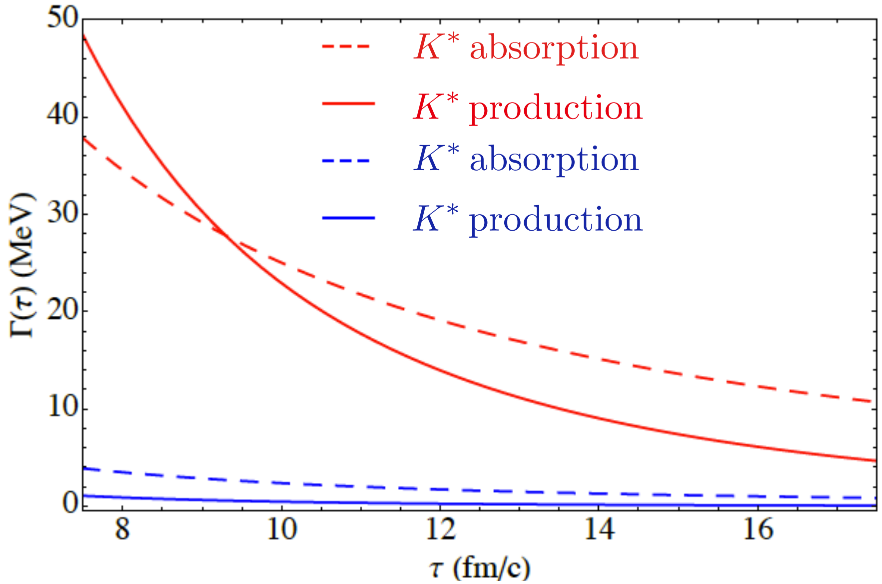
$$T_f = T_{f0}\, e^{-b\mathcal{N}}$$

$$\mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$





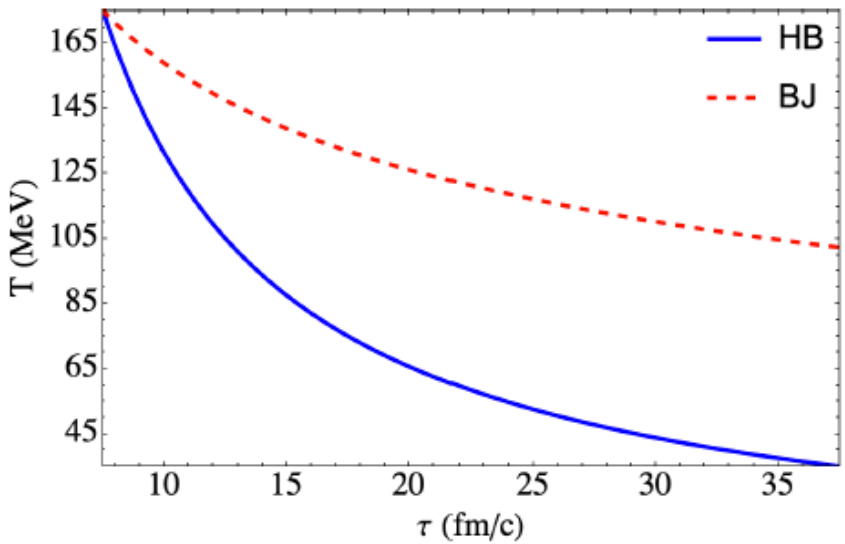
Reaction Rate



Martinez et al., arXiv:1708.05784

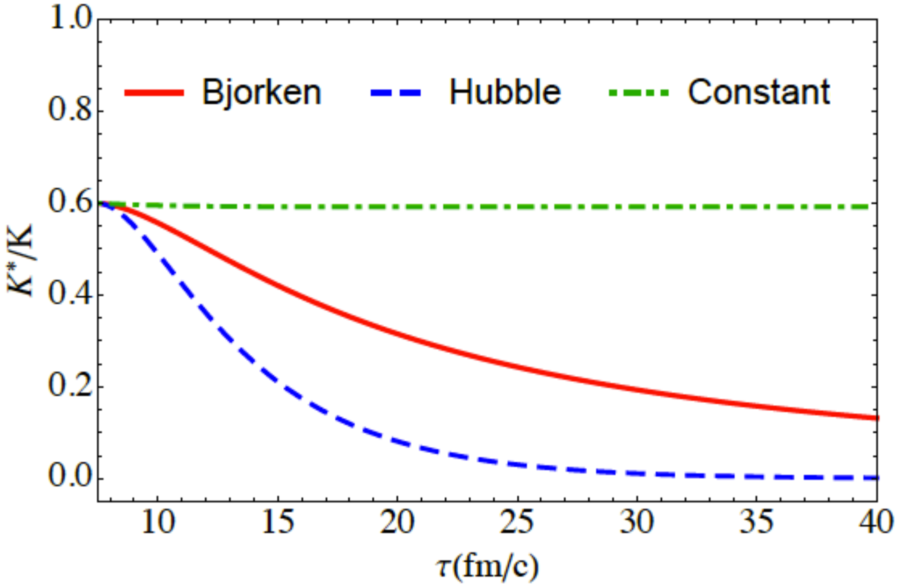
S. Cho, S.H. Lee, arXiv:1509.04092

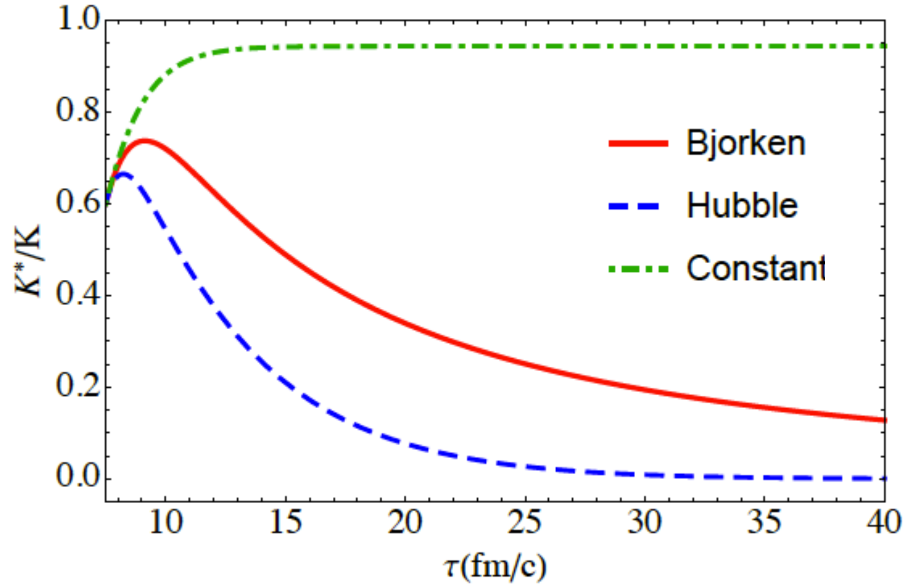
Effect of cooling



$$T(\tau) = T_h \left(\frac{\tau_h}{\tau}\right)^{\frac{1}{3}}$$ Bjorken

$$T(\tau) = T_h \left(\frac{\tau_h}{\tau}\right)$$ Hubble



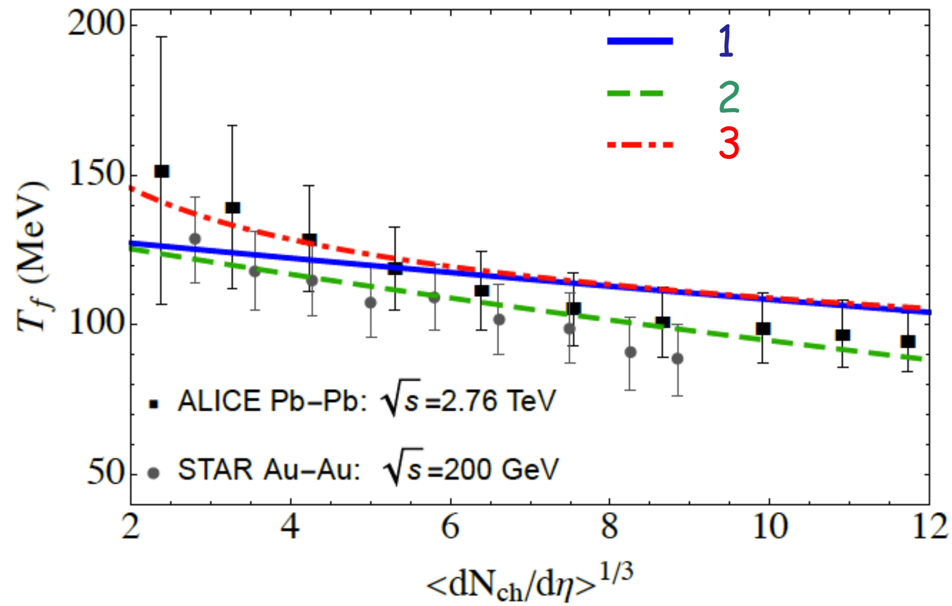


Effect of the parametrization of T_f

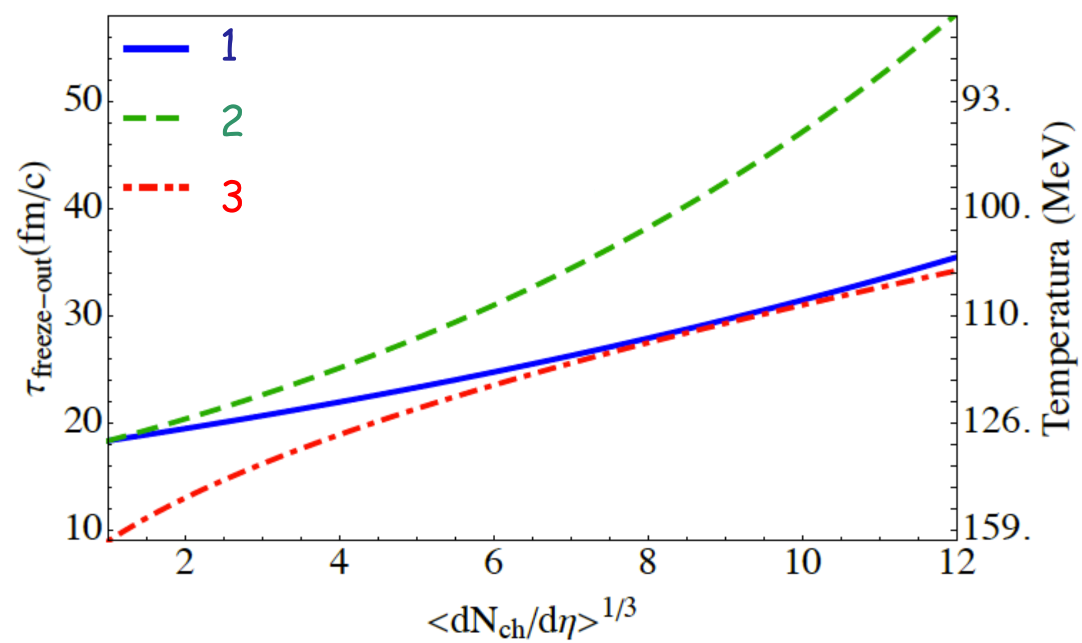
1 $T_f = 132\, e^{-0.02\, \mathcal{N}}$

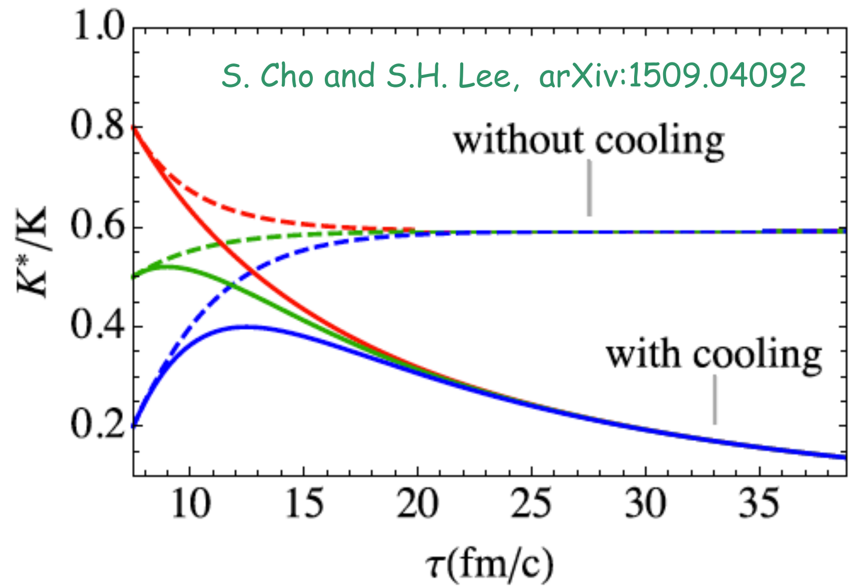
2 $T_f = 134\, e^{-0.035\, \mathcal{N}}$

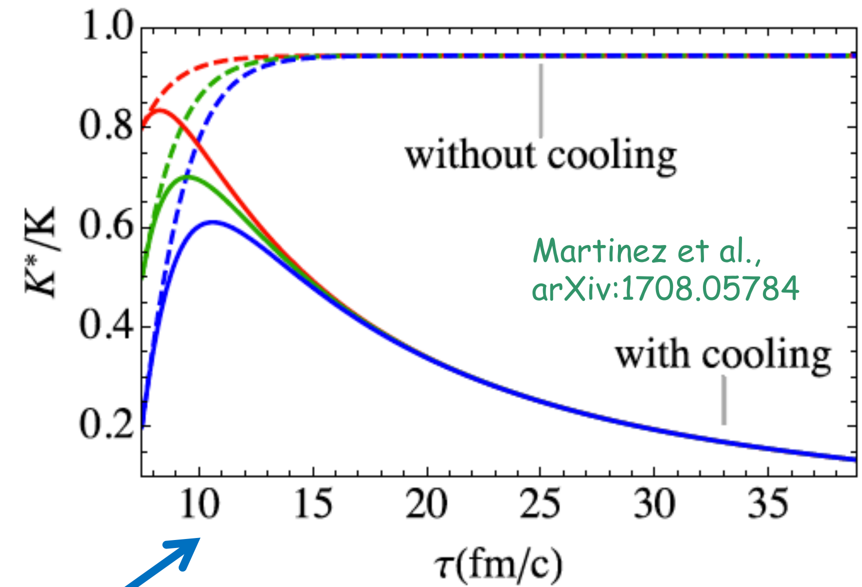
3 $T_f = 165\, e^{-0.18\, \mathcal{N}}$



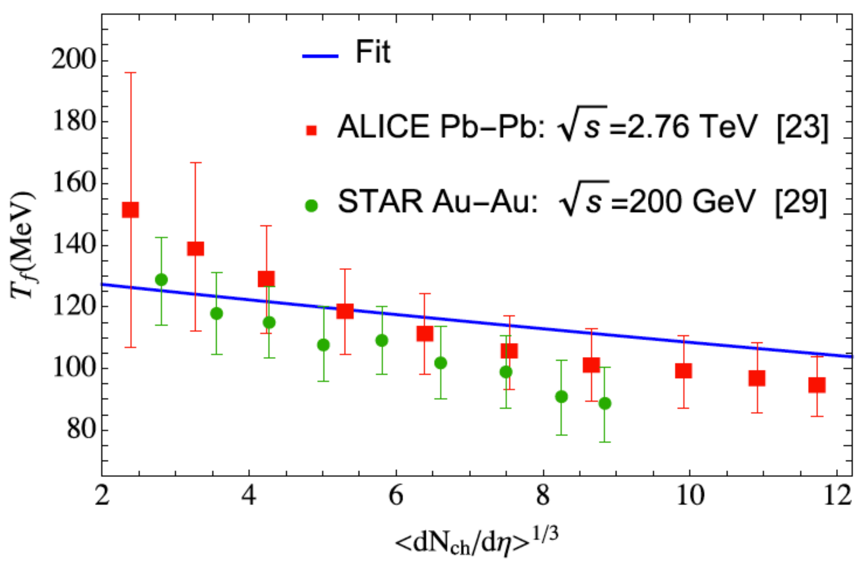
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$

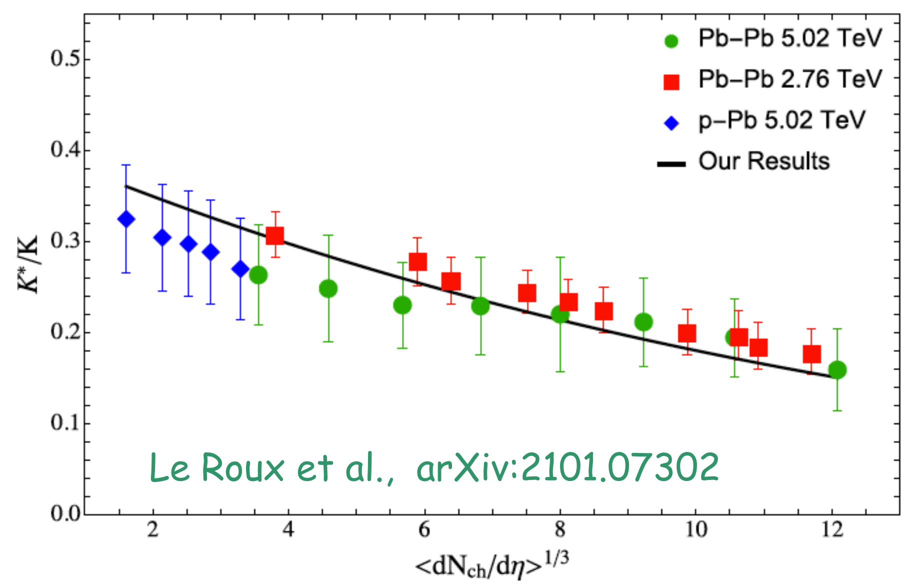






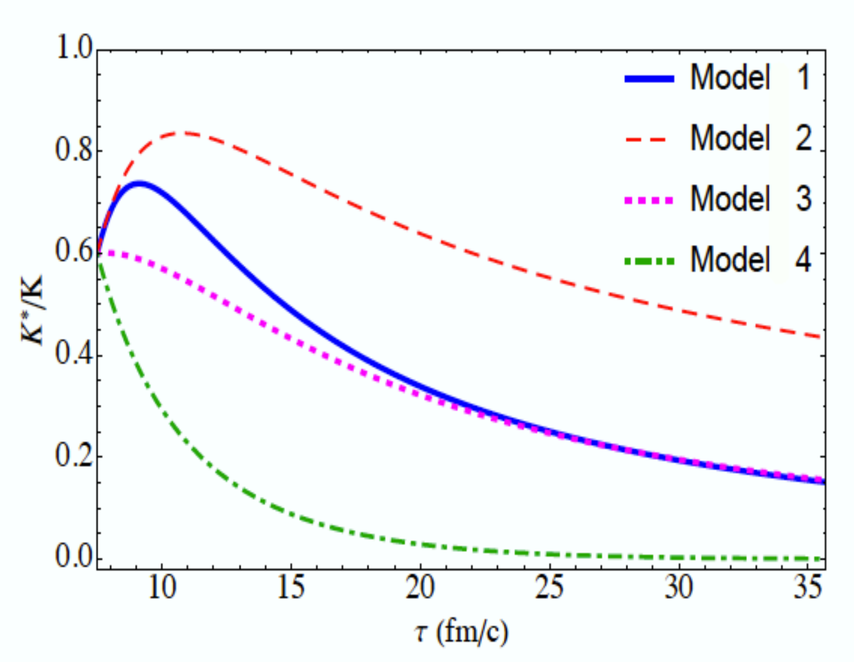
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$

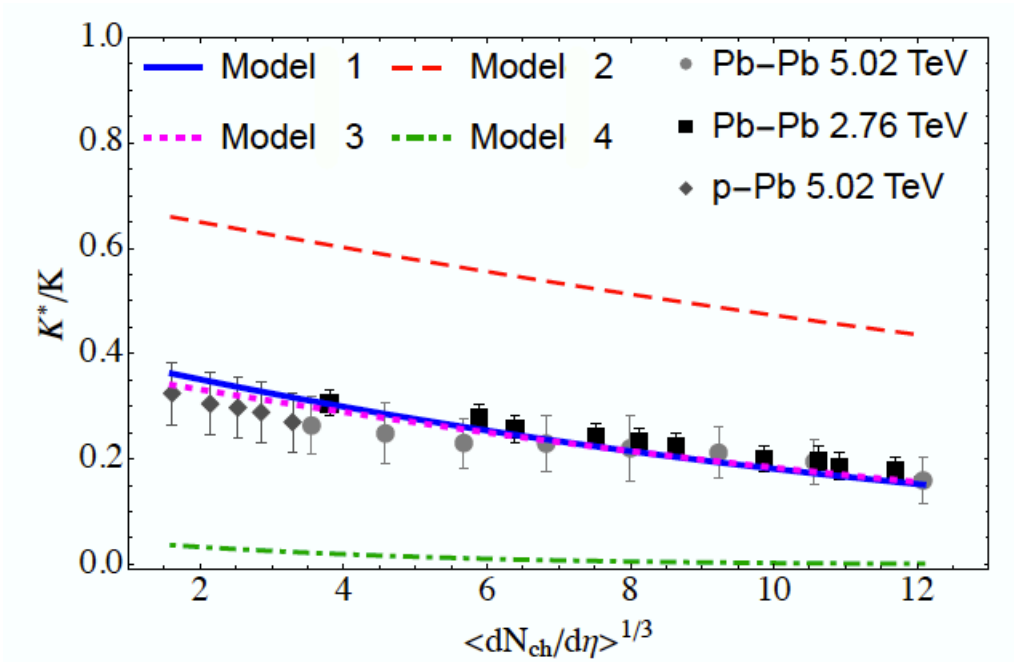




Which reaction is more important?

	$K^*\pi \leftrightarrow K\rho$	$K^*\rho \leftrightarrow K\pi$	$K^* \to K\pi$	$K\pi \to K^*$
Model 1	✓	✓	✓	✓
Model 2	✓	✓		
Model 3			✓	✓
Model 4			✓	





C.~Le Roux and F.~S.~Navarra, J. Phys. Conf. Ser. {2340}, 012010 (2022)

Summary

To describe the data we need:

- K* decay and formation
- Cooling
- System dependent freeze-out

D^* / D Ratio

Lagrangians -> Amplitudes -> Cross Sections -> Thermal Cross Sections

Evolution equations -> Expansion and cooling -> Freeze-out

Abreu, FSN and Vieira, arXiv:2209.03814

Decay: $D^* \to D + \pi$ $\Gamma(D^*) \simeq 1\,\mathrm{MeV}$ $\tau_{life} = \dfrac{1}{\Gamma(D^*)} \simeq 200\,\mathrm{fm}$

Not relevant !

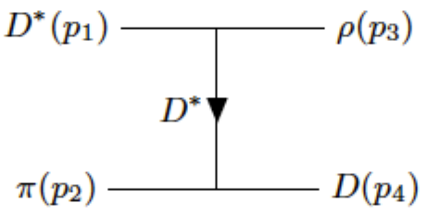
Interactions with rhos and pions

$$\mathcal{L}_{\pi D D^*} = i g_{\pi D D^*} D^{*\mu} \vec{\tau} \cdot (\bar{D} \partial_\mu \vec{\pi} - \partial_\mu \bar{D} \vec{\pi})$$
$$\mathcal{L}_{\rho D D} = i g_{\rho D D} (D \vec{\tau} \partial_\mu \bar{D} - \partial_\mu D \vec{\tau} \bar{D}) \cdot \vec{\rho}^\mu ,$$
$$\begin{aligned} \mathcal{L}_{\rho D^* D^*} = i g_{\rho D^* D^*} \big[& (\partial_\mu D^{*\nu} \vec{\tau} \bar{D}^*_\nu - D^{*\nu} \vec{\tau} \partial_\mu \bar{D}^*_\nu) \cdot \vec{\rho}^\mu \\ & + (D^{*\nu} \vec{\tau} \cdot \partial_\mu \vec{\rho}_\nu - \partial_\mu D^{*\nu} \vec{\tau} \cdot \vec{\rho}_\nu) \bar{D}^{*\mu} \\ & + D^{*\mu} (\vec{\tau} \cdot \vec{\rho}^\nu \partial_\mu \bar{D}^*_\nu - \vec{\tau} \cdot \partial_\mu \vec{\rho}^\nu \bar{D}^*_\nu) \big] , \end{aligned}$$
$$\mathcal{L}_{\pi D^* D^*} = -g_{\pi D^* D^*} \epsilon^{\mu\nu\alpha\beta} \partial_\mu D^*_\nu \pi \partial_\alpha \bar{D}^*_\beta ,$$
$$\mathcal{L}_{\rho D D^*} = -g_{\rho D D^*} \epsilon^{\mu\nu\alpha\beta} (D \partial_\mu \rho_\nu \partial_\alpha \bar{D}^*_\beta + \partial_\mu D^*_\nu \partial_\alpha \rho_\beta \bar{D})$$

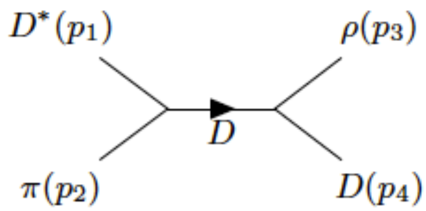
All couplings and form factors calculated with QCD sum rules!

M.~E.~Bracco, M.~Chiapparini, F.~S.~Navarra and M.~Nielsen, arXiv:1104.2864

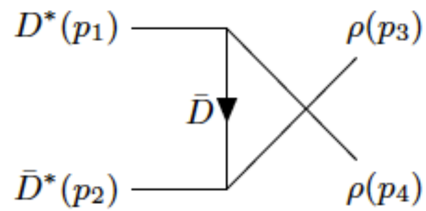
Amplitudes



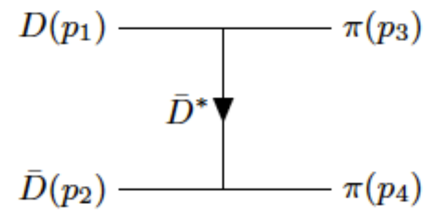
(1.a)



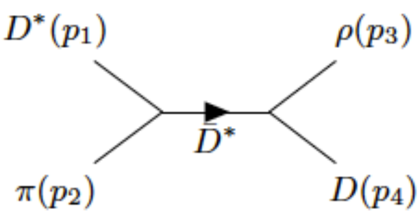
(1.b)



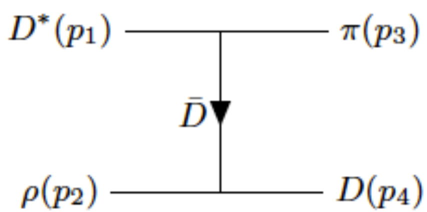
(5.d)



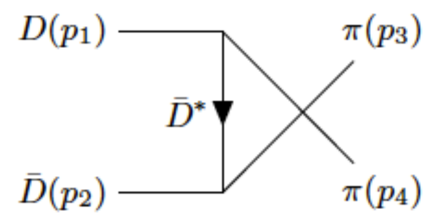
(6.a)



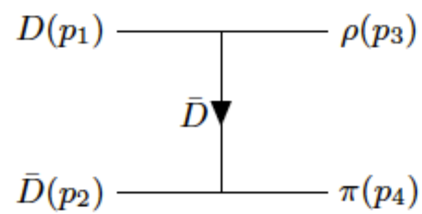
(1.c)



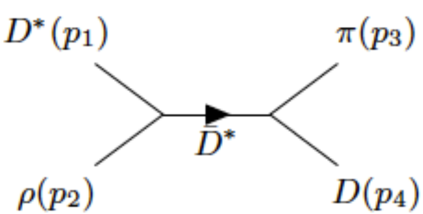
(2.a)

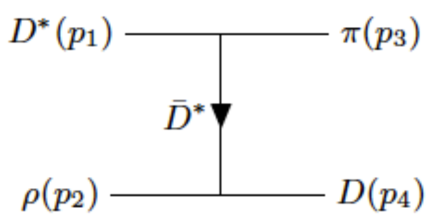


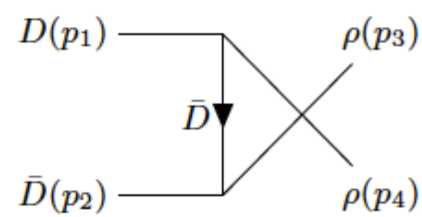
(6.b)

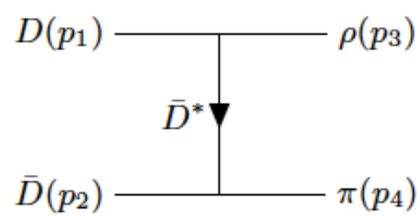


(7.a)









Expansion, cooling and initial conditions

$$T(\tau) = T_C - (T_H - T_F)\left(\frac{\tau - \tau_H}{\tau_F - \tau_H}\right)^{\frac{4}{5}},$$

$$V(\tau) = \pi\left[R_C + v_C(\tau - \tau_C) + \frac{a_C}{2}(\tau - \tau_C)^2\right]^2 \tau c,$$

TABLE II. Parameters used in Eq. (12) for central $Pb - Pb$ collisions at $\sqrt{s_{NN}} = 5$ TeV [25].

v_C (c)	a_C (c^2/fm)	R_C (fm)
0.5	0.09	11
τ_C (fm/c)	τ_H (fm/c)	τ_F (fm/c)
7.1	10.2	21.5
T_C(MeV)	T_H(MeV)	T_F(MeV)
156	156	115
N_c	$N_\pi(\tau_F)$	$N_\rho(\tau_F)$
14	2410	179
$N_D(\tau_H)$	$N_{D^*}(\tau_H)$	
4.7	6.3	

EXHIC, arXiv:1702.00486

Time evolution and multiplicities

$$\frac{dN_{D^*}}{d\tau} = \langle\sigma_{D\rho\to D^*\pi}v_{D\rho}\rangle n_\rho(\tau)N_D(\tau) - \langle\sigma_{D^*\pi\to D\rho}v_{D^*\pi}\rangle n_\pi(\tau)N_{D^*}(\tau) + \langle\sigma_{D\pi\to D^*\rho}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau)$$
$$- \langle\sigma_{D^*\rho\to D\pi}v_{D^*\rho}\rangle n_\rho(\tau)N_{D^*}(\tau) + \langle\sigma_{\pi\rho\to D^*\bar{D}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau) - \langle\sigma_{D^*\bar{D}\to\rho\pi}v_{D^*\bar{D}}\rangle n_{\bar{D}}(\tau)N_{D^*}(\tau)$$
$$+ \langle\sigma_{\pi\pi\to D^*\bar{D}^*}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{D^*\bar{D}^*\to\pi\pi}v_{D^*\bar{D}^*}\rangle n_{\bar{D}^*}(\tau)N_{D^*}(\tau) + \langle\sigma_{\rho\rho\to D^*\bar{D}^*}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D^*\bar{D}^*\to\rho\rho}v_{D^*\bar{D}^*}\rangle n_{\bar{D}^*}(\tau)N_{D^*}(\tau) + \langle\sigma_{D\pi\to D^*}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau) - \langle\Gamma_{D^*}\rangle N_{D^*}(\tau),$$

$$\frac{dN_D}{d\tau} = \langle\sigma_{\pi\pi\to D\bar{D}}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{D\bar{D}\to\pi\pi}v_{D\bar{D}}\rangle n_{\bar{D}}(\tau)N_D(\tau) + \langle\sigma_{\rho\rho\to D\bar{D}}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D\bar{D}\to\rho\rho}v_{D\bar{D}}\rangle n_{\bar{D}}(\tau)N_D(\tau) + \langle\sigma_{D^*\pi\to D\rho}v_{D^*\pi}\rangle n_\pi(\tau)N_{D^*}(\tau) - \langle\sigma_{D\rho\to D^*\pi}v_{D\rho}\rangle n_\rho(\tau)N_D(\tau)$$
$$+ \langle\sigma_{D^*\rho\to D\pi}v_{D^*\rho}\rangle n_\rho(\tau)N_{D^*}(\tau) - \langle\sigma_{D\pi\to D^*\rho}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau) + \langle\sigma_{\pi\rho\to D^*\bar{D}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D^*\bar{D}\to\rho\pi}v_{D^*\bar{D}}\rangle n_{\bar{D}}(\tau)N_{D^*}(\tau) + \langle\Gamma_{D^*}\rangle N_{D^*}(\tau) - \langle\sigma_{D\pi\to D^*}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau),$$

$$n_i(\tau) \approx \frac{1}{2\pi^2}\gamma_i g_i m_i^2 T(\tau) K_2\left(\frac{m_i}{T(\tau)}\right) \qquad N_i = n_i V$$

$$\tau_f = \tau_h\left(\frac{T_H}{T_F}\right)^3 \qquad T_F = T_{F0}e^{-b\mathcal{N}} \qquad \longrightarrow \qquad \tau_F \propto e^{3b\mathcal{N}}$$

Summary

K* / K ratio can be well understood with a hadron gas phase

K* decay and formation are the dominant reactions

Cooling and system size dependence of the freeze-out are crucial

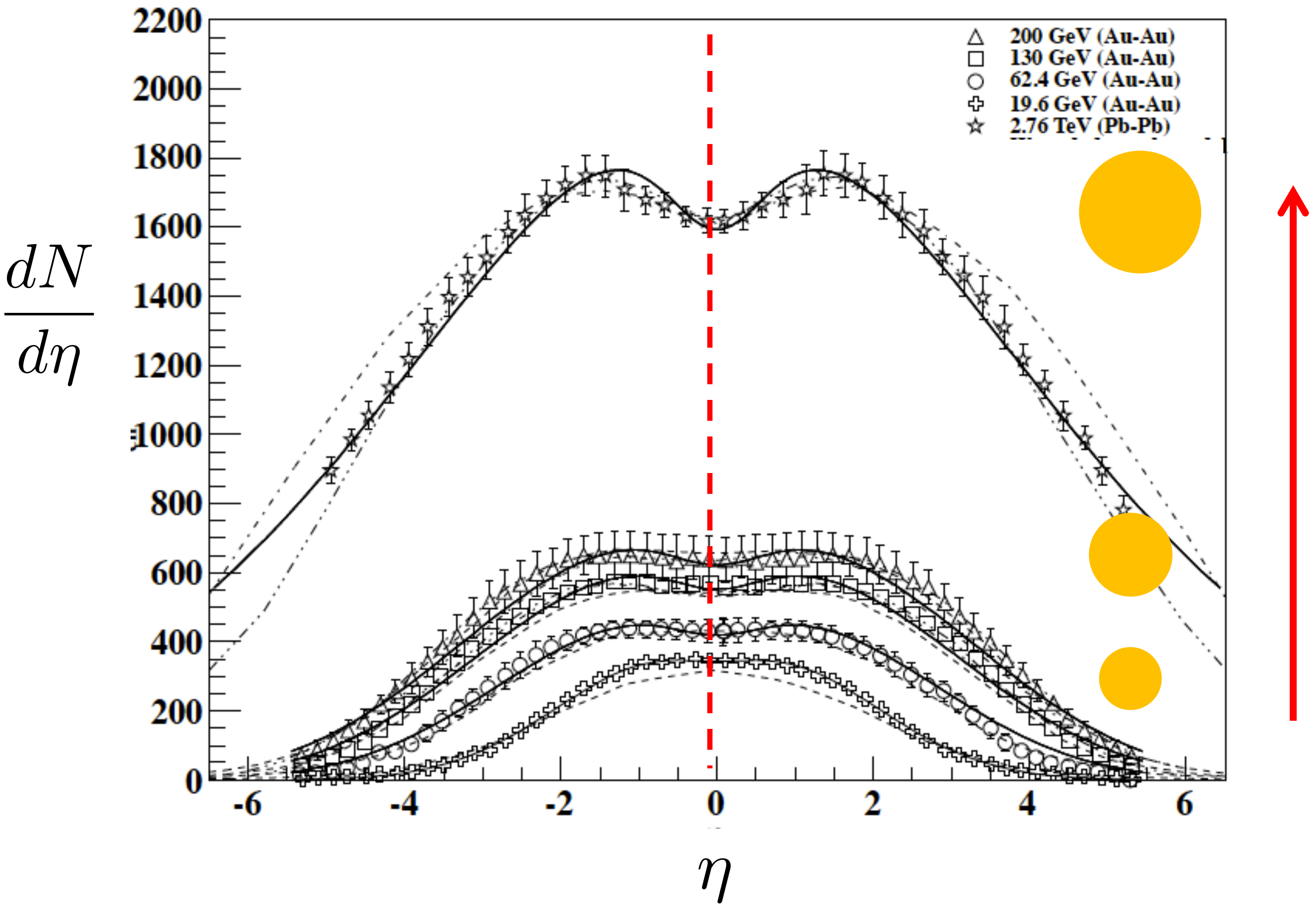
Predictions for the D* / D ratio

Thank you very much !!!

Back-ups

System Size

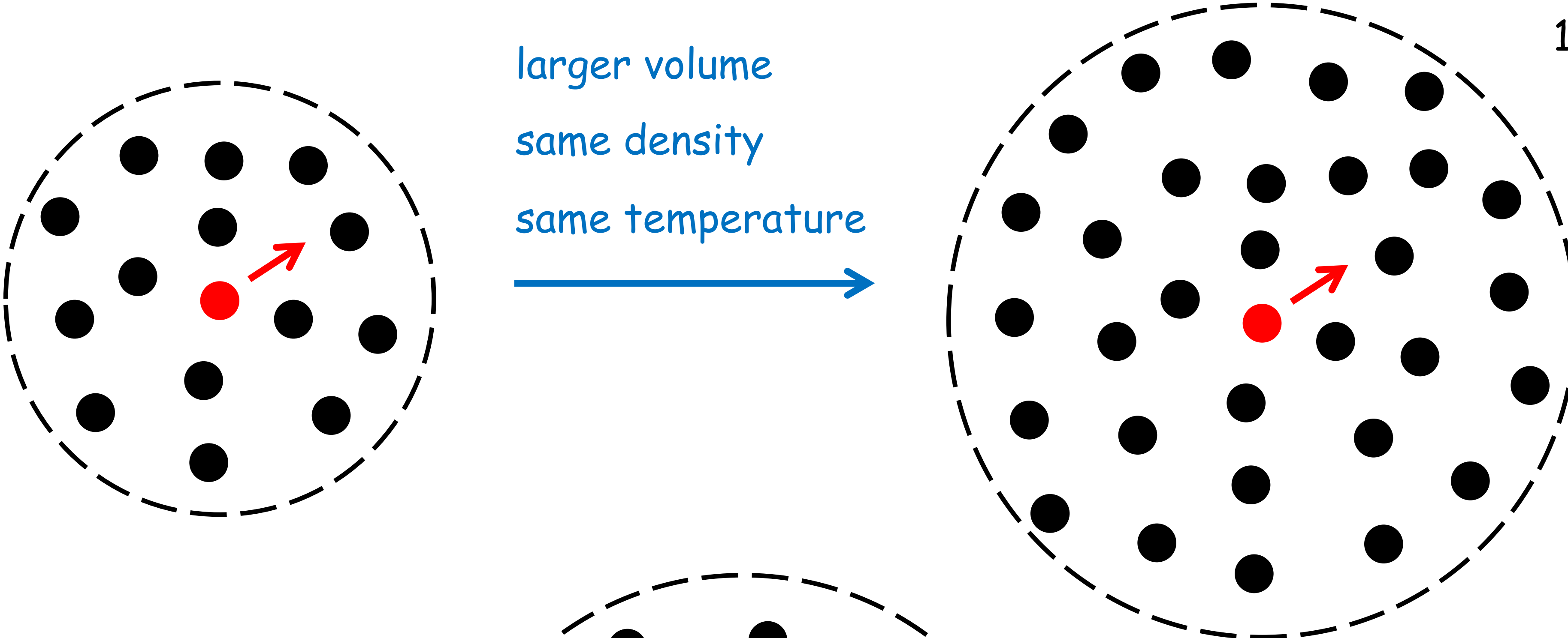
$$\left(\frac{dN}{d\eta}\right)_{\eta=0} \qquad \mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$



More mesons produced

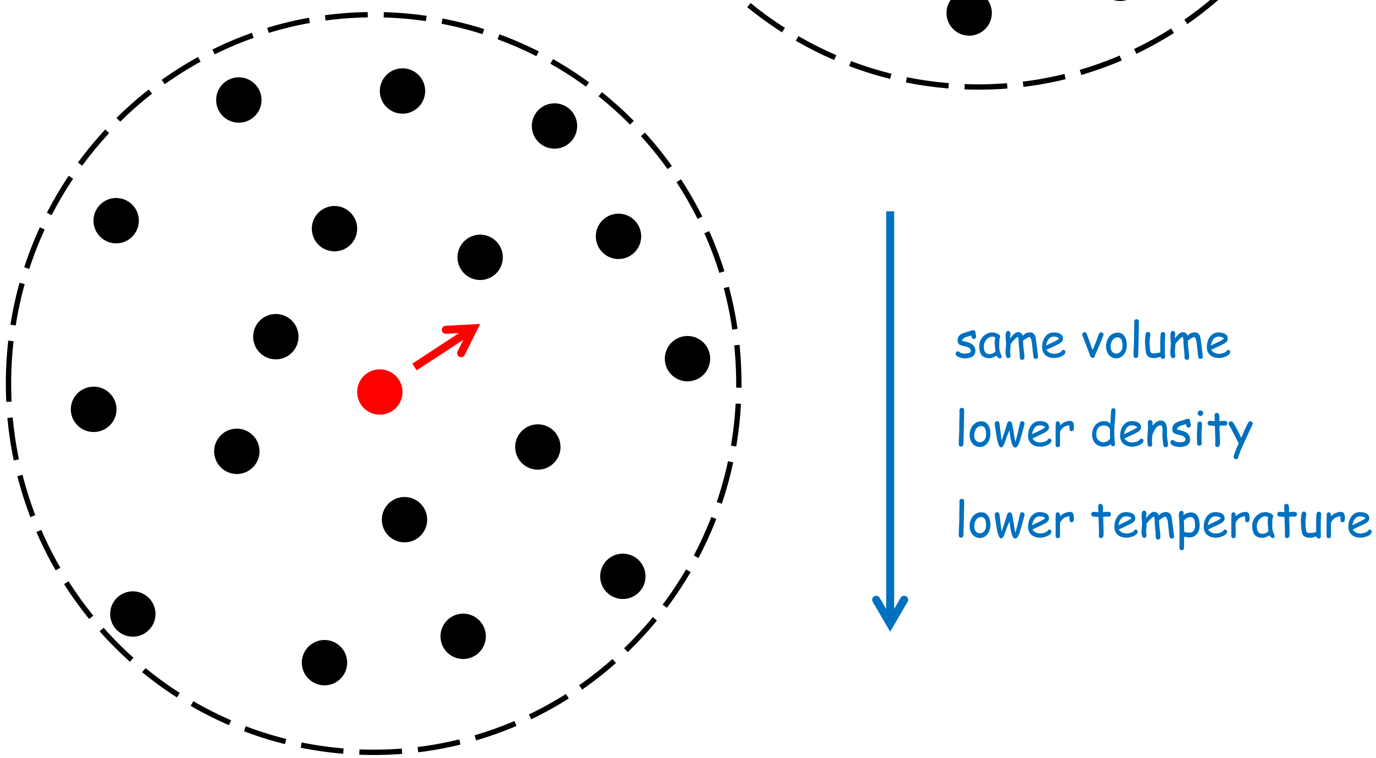
Larger volume

Lives longer



Freeze-out:

$$l = \frac{1}{n\,\sigma} = R$$



Back to Giorgio

$$\Gamma(D^*) \simeq 1\,\mathrm{MeV} \quad \tau_{life} = \frac{1}{\Gamma(D^*)} \simeq 200\,\mathrm{fm}$$

Rapidity and pt dependence of R

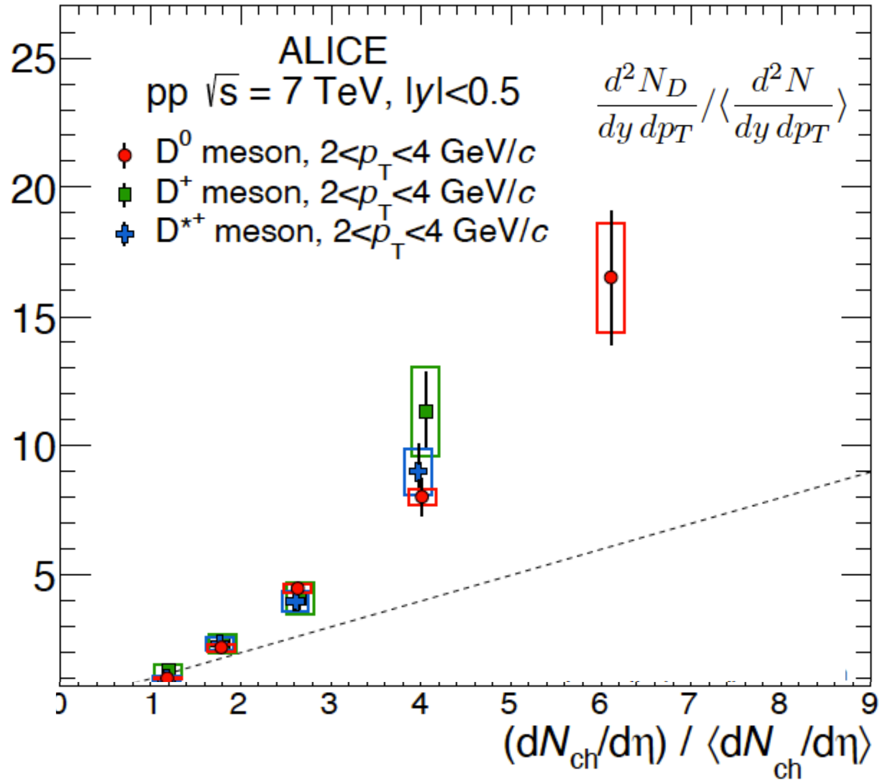
Freeze-out e tamanho

SU(4)

Gamma térmico = loops

System size and number of charm quarks

$$\frac{\frac{d^2 N_D}{dy\,dp_T}}{\langle \frac{d^2 N}{dy\,dp_T} \rangle}$$



ALICE, JHEP (2015), arXiv:1505.00664

$$\frac{d^2 N_D}{dy\,dp_T} / \langle \frac{d^2 N}{dy\,dp_T} \rangle = \alpha' \left(\frac{dN_{ch}}{d\eta} / \langle \frac{dN_{ch}}{d\eta} \rangle \right)^{\beta}$$

$$\beta = 1.6$$

Assume that:

$$N_D \propto (\mathcal{N}^3)^{\beta}$$

$$N_c \propto (\mathcal{N}^3)^{\beta}$$

Fix the constant using EXHIC estimates:

$$N_c = 7.9 \times 10^{-5}\, \mathcal{N}^{4.8}$$

Lifetime as a function of the size